DOCUMENT RESUME

ED 300 251 SE 050 087

TITLE Focus on the Future: A National Action Plan for Career-Long Education for Engineers.
INSTITUTION National Academy of Engineering, Washington, D.C.
PUB DATE 88
NOTE 84p.; Colored pages may not reproduce well.
AVAILABLE FROM NAE Program Office, National Academy of Engineering, 2101 Constitution Avenue, NW, Washington, DC 20418 (free while supply lasts).
PUB TYPE Reports - General (140)

EDRS PRICE MF01/PC04 Plus Postage.
DESCRIPTORS Adult Education; *Engineering Education; *Engineers; Government Role; Higher Education; Inservice Education; *Lifelong Learning; *Postsecondary Education; *Professional Associations; *Professional Continuing Education; Professional Development; Professional Occupations; Refresher Courses

ABSTRACT

This report had its origins in a request by the Council of the National Academy of Engineering to its Education Advisory Board (EAB) to consider selected aspects of the fundamental structure of engineering education. There was professional agreement that probably the least effective and appreciated aspect of engineering education was that which occurred after initial, formal campus training, and that rapidly changing technology and global economic competition would call for even more effective efforts for career-long education in the future. Part 1 of the report establishes the rationale for strengthening career-long education for engineers. Part 2 suggests a national action plan for such career-long education by discussing the need for: (1) a national coalition; (2) a systems approach; (3) employer support for education objectives; (4) a broadening of the mission of educational institutions; (5) government action to foster career-long education; and (6) increased leadership from professional societies and other groups. In addition to a reference list of 25 citations, the document contains four appendices which address the "Return on Investment in Career-Long Education"; "Adult Learning and the Engineer"; "Characteristics of a Successful Education Program in a Large or Medium-Size Company"; and "Study Contributors." (PK)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

SE

ED300251

Focus on the Future

A NATIONAL ACTION PLAN FOR CAREER-LONG EDUCATION FOR ENGINEERS

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

X This document has been reproduced as received from the person or organization originating it.

☐ Minor changes have been made to improve reproduction quality.

• Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY

Carrie Swandaki

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

National Academy of Engineering

SE 050 087

Focus on the Future:

A National Action Plan for Career-Long Education for Engineers

Report of the Committee on
Career-Long Education for Engineers

National Academy of Engineering

Washington, D.C. 1988

NOTICE: The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers.

The members of the committee responsible for this report were drawn from the National Academy of Engineering and were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed according to the procedures of the National Research Council Report Review Committee by members of the National Academy of Engineering other than the authors. The work on which this publication is based was performed under Cooperative Agreement #ENG 8519387 between the National Science Foundation and the National Academy of Sciences.

The material is also based in part on work supported by the National Academy of Engineering Technology Agenda Program.

Available from
Program Office, NAS 050
National Academy of Engineering
2101 Constitution Avenue, N.W.
Washington, DC 20418
Phone: (202) 334-1650
Printed in the United States of America

COMMITTEE ON CAREER-LONG EDUCATION FOR ENGINEERS

Thomas L. Martin, Jr., *Chairman*, Illinois Institute of Technology (emeritus)
Jose B. Cruz, University of California, Irvine
Martin Goland, Southwest Research Institute
Robert C. Gooding, Columbia Research Corporation
Serge Gratch, GMI Engineering & Management Institute
Craig Marks, Allied Signal, Inc.
James D. Meindl, Rensselaer Polytechnic Institute
Jack N. Nielson, National Aeronautics and Space Administration
Thomas K. Perkins, ARCO Oil & Gas Company
Kenneth A. Roe, Burns and Roe, Inc.
Chauncey Starr, Electric Power Research Institute, Inc.
Dale F. Stein, Michigan Technological University
Leo J. Thomas, Eastman Kodak Company
Eric A. Walker, Pennsylvania State University
F. Karl Willenbrock, American Society for Engineering Education

Advisers
Nell P. Eurich, Academy for Educational Development
Lyle D. Feisel, State University of New York at Binghamton
Bernard P. Goldsmith, Carnegie Mellon University
Charles W. Hoover, Jr., AT&T Bell Laboratories
Marc Tucker, Carnegie Forum on Education and the Economy

Staff
Pamela H. Atkinson, NAE Fellow, Study Director
Jesse H. Ausubel, Director, NAE Program Office
Caroline G. Anderson, Administrative Secretary
Penelope J. Gibbs, Administrative Supervisor
H. Dale Langford, NAE Editor

EDUCATION ADVISORY BOARD

Daniel Berg, *Chairman*, Rensselaer Polytechnic Institute
Norman R. Augustine,* Martin-Marietta Corporation
C. Gordon Bell,* Ardent Computer Corporation
Robert C. Dean, Jr., Synosys Corporation
James J. Duderstadt, University of Michigan
Jerrier A. Haddad,* IBM Corporation (retired)
Paul C. Jennings, California Institute of Technology
Thomas H. Lee, Massachusetts Institute of Technology
Kenneth G. McKay,* AT&T Bell Laboratories (retired)
Russell G. Meyerand, Jr., United Technologies Research Center
Ascher H. Shapiro, Massachusetts Institute of Technology
William P. Slichter, AT&T Bell Laboratories
Johannes Weertman, Northwestern University

*Term expired 30 June 1988.

Foreword

Accelerating technological change, the basis for economic growth, demands that a nation have an engineering work force whose training is equal to or better than that of its industrial partners and competitors. An engineer's education, like that of a physician, can never cease if we want to have such an engineering work force. Career-long education that is of high quality and widely available to a motivated engineering work force is the only answer. Only with such highly trained engineers will U.S. industries maintain and strengthen their competitive position in the global marketplace.

In the past decade numerous groups have examined the issue of competitiveness and economic growth (National Academy of Engineering, 1988). Without exception they emphasize the importance of keeping U.S. engineers continually educated and trained in the use of new tools, processes, and systems that can help improve performance and productivity. The arguments are well supported by data that emphasize the need for action, but there is insufficient action beyond the existing efforts in career-long education. *Continuing Education of Engineers*, a National Research Council report prepared in 1985 at the request of the National Academy of Engineering, provides a useful profile of career-long education in the United States. However, reports on education too often gather dust on shelves.

One reason is that recommendations are only as effective as the willingness and ability of potential implementing organizations. There is no single continuing focus at the national level that can coordinate, monitor, urge, and advocate action. The key to enduring progress appears to lie in developing a strategy that will bring into being mechanisms that can follow through on recommendations. This goal represents a challenge to the engineering community as a whole, from industry and professional societies to government agencies and the university community.

The Committee on Career-Long Education for Engineers was asked to develop a plan of action as well as explore the need for a mechanism to give impetus to, provide advocacy for, and monitor the implementation of progress on career-long education of engineers.

Many of the recommendations of this committee have been voiced by other groups; they reiterate themes that surface whenever knowledgeable people in the engineering community are asked to review the issue.

The Committee believes the magnitude and urgency of the problem have grown and that it is time for a concentrated response by the engineering community. The economic consequences of failure to act in a technologically competitive world will be a continuing degradation of the relative excellence of the engineering and technological enterprise of the United States.

This report identifies the need for leadership at the national level, points out the benefits of investment in career-long education, highlights successful models of engineering education programs and policies, and reaffirms the need for continuous career-long education with action plans for the future. Recommendations for action are made to those elements of the engineering community that are directly involved and have the most to contribute to developing the knowledge, skills, and talent of engineering professionals; this includes not only industry, where most engineers work, but also colleges and schools of engineering throughout the country, as well as professional societies. Recommendations are also made to government to assume more responsibility for career-long education for engineers.

Through concerted action on career-long education, the U.S. engineering community can help ensure the technological vitality of the profession and the economic vitality of the nation.

Robert M. White
President
National Academy of Engineering

References

National Research Council. 1985. Continuing Education of Engineers. Committee on the Education and Utilization of the Engineer, Panel on Continuing Education, Morris A. Steinberg, Chairman. Washington, D.C.: National Academy Press.

National Academy of Engineering. 1988. The Technological Dimensions of International Competitiveness. Washington, D.C.: National Academy of Engineering.

Preface and Acknowledgments

In the course of its work, the Committee on Career-Long Education for Engineers (CLEFE) was repeatedly impressed by the efforts of many groups active in career-long education. These include not only the efforts of firms and universities, but also those by many engineering professional societies, for example, the American Society for Metals, the Institute of Electrical and Electronics Engineers, and the National Society of Professional Engineers. They also include efforts by a variety of other organizations, such as the American Society for Training and Development, the National Technological University, the Association for Media-Based Continuing Engineering Education, the National University Continuing Education Association, and the Accreditation Board for Engineering and Technology. The work of such organizations as these provides the foundation of a national response to the need for enhanced career-long education for engineers. The Committee wishes to thank these groups for sharing information about their work and calls upon them and upon industry, government agencies, and individual engineers to continue vigorously all efforts to advance career-long education.

This report had its origins in a request by the Council of the National Academy of Engineering to its Education Advisory Board (EAB) to consider selected aspects of the fundamental structure of engineering education. The EAB and the NAE's Industry Advisory Board concurred that probably the least effective and appreciated aspect of engineering education was that which occurred after initial, formal campus training, and that rapidly changing technology and global economic competition would call for ever more effective efforts for career-long education in the future. The Academy appointed the Committee on Career-Long Education for Engineers, all members of the NAE, as well as a group of expert advisers, and a work plan was developed. The charter of the Committee stressed developing an action

plan based on available analyses and information. Financial support was provided both from the NAE's independent funds through its Technology Agenda program and by the National Science Foundation.

Over the course of 18 months, the CLEFE Committee met five times and also held a workshop and an especially valuable meeting with representatives of some 30 of the engineering professional societies. The Committee was supported with imagination and enthusiasm by the efforts of Pamela H. Atkinson, NAE Fellow, on leave from the Televised Instruction Program in the College of Engineering at the University of California, Berkeley. Daniel Berg, Jerrier A. Haddad, and Morris A. Steinberg provided valuable guidance on behalf of the EAB. Jesse H. Ausubel, director of the NAE Program Office, provided overall continuity and management support for the project. I wish to thank the members of the Committee for their persistence and hard work in bringing this project to completion and members of the NAE staff, including Caroline G. Anderson, Penelope J. Gibbs, H. Dale Langford, and James R. Porter for their able support.

However, I think it is necessary to emphasize before closing that more than reports are required. The problems of technical obsolescence and formation of engineering intellectual capital must be addressed by ever-expanding action, and no single group has the resources to respond to the diversity of needs. As outlined in the report that follows, greater effort is required of all parties in working toward an overall coalescence of the engineering community in behalf of career-long education for engineers.

Thomas L. Martin, Jr.
Chairman, Committee on Career-Long Education for Engineers

Contents

Executive Summary 1

Part 1 The Rationale for Strengthening Career-Long Education for Engineers

1. Background 7
2. The Forcing Factors 10
3. Intellectual Capital 17
4. Benefits to Engineers 20
5. The Current Situation and Its Origins 22
6. A Technological Opportunity 31
7. The Structural Problem and the Need 34

Part 2 A National Action Plan for Career-Long Education for Engineers

1. The Need for a Nationwide Coalition 39
2. The Need for a Systems Approach 41
3. The Need for Employer Support of Education Objectives 42
4. The Need to Broaden the Mission of Educational Institutions 43
5. The Need for Government Action to Foster Career-Long Education . 45
6. The Need for Increased Leadership from Professional Societies and Other Groups 46

References 51

Appendixes

A. Return on Investment in Career-Long Education 53
Charles W. Hoover, Jr.

B. Adult Learning and the Engineer 59
Pamela H. Atkinson
C. Characteristics of a Successful Education Program in a Large or Medium-Size Company 69
D. Study Contributors 71

Focus on the Future:

A National Action Plan for Career-Long Education for Engineers

Executive Summary

The ability to compete in the international marketplace is determined in critical ways by a nation's resources of engineering and scientific *intellectual* capital. The high quality of recent graduates from engineering colleges in the United States provides a strong base for formation and growth of this capital. A combination of circumstances, however, may cause the supply and quality of engineering intellectual capital of the United States to be insufficient to meet future goals for economic growth, security, and improvements in quality of life. These circumstances include the fierce worldwide economic competition, rapid technological advancement, the changing pool of people in the United States from which our future engineering personnel is likely to come, serious questions about the quality of public education for young people in mathematics and science, and increasing needs and opportunities for engineers in organizational functions where they previously were seldom found.

Investment in post-baccalaureate, career-long education of practicing engineers can help overcome shortfalls of engineering intellectual capital. Indeed, compared to the investments already made in the resource, the increment for career-long education may be modest and strongly justified. Benefits to the nation and to employers from enhanced programs of career-long education appear to be considerable.

Equally important as the national need is the need for individual engineers to participate in continuous career development. A career typically lasts 35 to 40 years. The value of professional engineering expertise depreciates rapidly in many areas, so that obsolescence may become a serious problem as soon as 3 to 7 years after completion of formal education. Career-long education helps an engineer perform

more effectively on a current job, prepare for a new job, and gain greater personal satisfaction from work.

In the Committee's judgment, investment and participation in career-long education remain below desirable levels. This is attributable in large part to the structural reality of a system in which costs and benefits are not always closely tied to one another in space or time. There is no doubt that career-long education of engineers is beneficial to society as a whole. However, there is no guarantee that the individual employer, the main source of financing for this education, will benefit directly from the investment in employees, who are free to change employment or may not make use of what they study. For the individual engineer, benefits of career-long education and the penalties for lack of such education typically accrue after, sometimes long after, the effort to obtain the education has been expended. The situation is especially troubling for engineers who do not work in large firms or central locations.

This report sets forth actions for institutions and for individual engineers to help preserve and expand intellectual capital resources to the benefit of the nation and the betterment of career prospects for all engineers. The Committee's principal recommendations are as follows:

1. A nationwide coalition should be formed to coordinate, monitor, urge, and advocate action for career-long education for engineers.

At the present time, there is a vacuum at the national level in the engineering community where there should be active and sustained leadership guiding and supporting engineering professional development through career-long education, although significant effort and leadership in individual engineering disciplines exist largely as a result of engineering society programs. No institution or group of individuals, no government agency or industrial association has assumed the critical role of advocacy and enhancement of career-long education across all engineering fields and for interdisciplinary areas. No single organization acts with broad and comprehensive nationwide effect as a source of information about how to provide career-long education or performs the function of informing and motivating engineers. The proposed coalition would serve as a catalyst for implementation of many of the other recommendations in this report. If requested by the other elements of the engineering community, the National Academy of Engineering should be willing to serve as the initiating organization to ensure formation of the coalition.

2. The engineering community as a whole must exercise leadership in

communicating the concept that engineering education is an integrated system. It must clarify the desired characteristics of the career-long portion of the system and improve the accessibility and other features of career-long education.

3. All private companies and other organizations that employ engineers should clarify and focus their educational objectives by linking those objectives with company goals. They should design infrastructures that encourage, support, and sustain a policy of career-long education from the highest level of the enterprise through managers and supervisors to the line engineer.

4. Engineering schools should reassess their role as professional schools with regard to the educational demands placed on the B.S. engineering professional by technological advances and other influences, and they should include the career-long education of engineers as part of their mission. More engineering schools can respond effectively to the educational needs of engineering professionals, in addition to responding to those of conventional, full-time students. Engineering schools should also make a concerted effort to impart to undergraduate and graduate engineers a desire for, and an understanding of the need for, career-long education.

5. The federal government and state governments should recognize the growing importance of career-long education for engineers and begin to assume more responsibility for it, taking appropriate actions to foster improvement of programs and facilitate participation, as well as support research in the field.

6. Engineering professional societies and other independent groups should assume an even stronger leadership role in the outreach to individual engineers.

Part 1

The Rationale for Strengthening Career-Long Education for Engineers

1

Background

Two reports published early in this decade have been especially important in reviewing the issues that affect the career-long education of engineers: *Lifelong Cooperative Education*, a report of the Massachusetts Institute of Technology (1982), and *A Nation at Risk*, the report of the National Commission on Excellence in Education (1983).

In 1982 the Massachusetts Institute of Technology's Department of Electrical Engineering and Computer Science celebrated its centennial. To assess the value of its program and set goals for the future, it convened a study committee of professionals in academe and industry to collect information from a variety of sources about the experience of engineers in school and working in their professions.

Interviews with industrial leaders confirmed that "creeping obsolescence among engineers" was a problem that needed immediate attention.

The result of this study was a set of well-defined recommendations to the Department of Electrical Engineering and Computer Science, the MIT engineering faculty at large, the administration, and, more broadly, the entire engineering community. The central thrust of the report was that education, particularly engineering education, is—or should be—a lifelong affair. The report said it succinctly:

> . . . [A] new pattern of engineering education [is required] . . . to meet the needs of a world characterised by rapid technological change and by engineering systems of growing complexity. In such a world, creative, responsible, and broadly knowledgeable engineers are a most precious resource, a resource whose quality cannot be replaced by quantity. . . . [To ensure its success] this new pattern of education would be distinguished by three major departures from past attitudes:
>
> - uninterrupted commitment to formal education on the part of engineers,
> - wholehearted support on the part of their employers of the notion that

study and teaching are necessary and valuable components of productive work,

- increased attention on the part of engineering faculties to the educational needs of working engineers of all ages (MIT, 1982, p. 2).

These three ideas and the avenues of opportunity they represent for the career-long education of engineers have helped frame many of the action recommendations of this report, and this committee acknowledges the vision of those who worked on the MIT study.

In 1983 *A Nation at Risk* was published. This was a report prepared by a national commission of educators, and it identified major problems in the U.S. primary through secondary school system. Convinced of the seriousness of the issues raised by these problems, the commission chose the title for their report to imply that the country's health and well-being were severely threatened by the poor education its youngest citizens were receiving in kindergarten through grade 12.

As this commission struggled to find solutions to these problems, they perceived the need for a national philosophy of education that would help prepare people for life in a rapidly changing world. The findings of their study convinced them that a formal education, historically defined as those years spent in school between the ages of 5 and 22, provides a good foundation of basic knowledge to prepare people for the challenging and dynamic world of the twenty-first century. But they realized the inadequacy of an education system that gives value to knowledge obtained primarily in the first trimester of an average life span and ignores not only the capacity of adults to continue to learn new things, but the increased need of all people—not just the young—to be well informed in a complex and highly technological environment. To be well educated and able to participate fully in the opportunities and advantages of the twenty-first century will require a commitment to lifelong learning, and not just from a select few, but from everyone.

The technological world changes constantly and soon will demand more technical proficiency from people than most individuals are prepared for. If U.S. citizens dedicate themselves to lifelong learning and become, as this commission recommended, a "Learning Society," they will be able to do more than just keep pace with technological change. They will be able to give shape and substance to the future and help ensure the future well-being of their children.

This level of participation in a lifelong process of education from early childhood through adulthood requires no less than a "coherent continuum of learning." Nowhere is this need more vital to the economic well-being of the country than in the education and training of its engineers.

Who or what combination of resources will supply the adult learner and develop the abilities our nation must have not just to maintain its economic position but to dramatically improve it in the face of worldwide competition and worldwide needs? What types of training and education are essential both for individual Americans and for the nation's imperatives? Which of our resources are most suitable to assist and should be rallied to help in providing the necessary programs? To restore America's leadership position solidly from its educational and training base requires the broadest assessment of the problem areas that undermine productivity and drain the human energy resources of the nation.

Training and retraining workers is a major challenge with complicated dimensions. . . . Well-conceived and implemented training programs could release an energy potential and raise productivity levels to the benefit of our society-and offset welfare costs. . . .

What is needed is vision or, at the very least, some long-range training programs that don't just "payoff" tomorrow, but benefit real education for America's future. . . .

. . . Strategic development for the long term is essential.

. . . [S]ociety must make the long-range capital investment in human resources and their development for the future of individuals and the national economy. . . .

. . .The new vision is one of continuing education for national renewal.

Eurich, 1985, pp. 133-139.

2

The Forcing Factors

Five factors are primarily responsible for the need for a heightened commitment to career-long education for engineers.

1. Internationalization of the engineering enterprise

The market for engineering services and the supplies of engineering skills have themselves become global. Firms based in the United States may contract for engineering development in Korea, India, or numerous other countries. Foreign-based firms in turn provide employment for many engineers in the United States. Both U.S. firms and individual U.S. engineers face stiffer competition than ever before, and many signs point toward a continuation of the trend to a global market for engineering. Competitive pressures often cause cancellation of projects, reassignments of engineers to other projects, and a great number of corporate failures. Technological leadership and excellence in quality are critical if the U.S. engineering enterprise is to compete successfully for work in the global economy.

2. Technological change

Virtually all fields of engineering include numerous examples of rapid erosion of the relevance of the engineer's knowledge base and how technological change has made career-long education of engineers even more important today than it was in the past. These changes range from the rise of new industries, such as biotechnology, for which there was no formally trained engineering work force, to the modernization of traditional industries. One recent report (National University Continuing Education Association, 1987) contains estimates of the half-life of an engineer's skills in 1986 at 2.5 years

in software engineering, 5 years in electrical engineering, and 7.5 years in mechanical engineering. A typical professional career lasts 35 to 40 years.

In part, engineering obsolecence is caused simply by the forward march of science. For example, the 1940s engineering graduate had to learn by continuing education all about the transistor—it did not exist when he or she was in college. The 1950s graduate had to learn about computers, and the 1960s graduate, fiber optics. Following are three brief cases from the automotive industry that show well the broader transformations under way and the demands they create:

Simultaneous engineering. Until the late 1970s, the design and development of a new car usually proceeded sequentially. Designers (once called stylists) and product planners developed the overall concept of the car, setting objectives for appearance, function, and cost. Then the design engineers analyzed each component and worked out the detailed design, taking into account such considerations as stresses and vibrations and often leaving the integration of all components to the end. Finally, the manufacturing engineers were given the task of figuring out how to manufacture the vehicle that had been designed, and the suppliers were given the job of figuring out how to supply certain components. In the last stage often it was found that some components had been designed in a manner that made their manufacture prohibitively expensive. At that point, negotiations were required to determine how the design could be changed to facilitate manufacture. At that late stage, invariably the design changes caused other problems. The result was not only extra engineering work but also deficiencies in the integration of the components, in the overall quality, and in the ease of maintenance and repair.

The reason that this clearly undesirable situation arose is that the various company functions were sharply divided. The prevailing theory of management was that compartmentalization on the basis of function was the most efficient method of organization. The engineering profession failed to point out the weaknesses of this management scheme.

In the late 1970s the U.S. automotive industry finally realized that the penalties associated with the traditional sequential process for the design and development of a new car were too great to tolerate. Major organizational changes were made to ensure that a complete team, including designers, product planners, design engineers, manufacturing engineers, purchasing people, and supplier representatives, would work on each new vehicle from the beginning, to ensure that each part could be made efficiently and with good quality. This team approach is described in the automotive industry as "simultaneous engineering." For the team to function smoothly, each member of the team must understand enough of the job of the other members of the team to be able to communicate efficiently with them. This, in turn, requires a much greater breadth than the previous, sequential approach.

This approach is not new to engineering as a whole. It has been used

in other industries (e.g., electronics) for decades, although it is quite new to the U.S. automotive industry.

Computer-integrated manufacturing. Computer-integrated manufacturing (CIM) aims at developing techniques whereby computer data bases developed in the design of a product are used directly, without the intermediary of hard copy, for engineering analysis (e.g., finite element methods of stress analysis or vibration analysis) and for setting up and controlling the manufacturing process (e.g., numerically controlled machining or other computer-controlled manufacturing processes). Although this may seem to be the obvious thing to do, it did not develop that way. From an aesthetic point of view, computer specification of the skin of an automobile as a continuum and the numerical specification of certain critical curves are sufficient. A much more detailed three-dimensional specification is required for stress analysis, however. In numerically controlled machining, it is necessary to specify the paths of the tools as they do the required cutting. The conversion from one type of numerical specification to another is far from a trivial mathematical problem, and real progress has been made only in the past few years.

Progress in the numerical specification of manufacturing process and the use of the techniques and methodologies developed for CIM require engineers to have much broader knowledge. The designers must have some understanding of the needs of the engineering analysts, and both must have some understanding of the needs of the manufacturing engineer. All three groups, of course, must have some understanding of the principles that govern the use of computers in engineering.

Electronics. The value of electronics in automobiles has increased by approximately a factor of 10 in the past decade. More important, electronics now dominates the function of many automobile components ranging from engines to suspensions, which until recently, required only classical mechanical engineering for their design.

On the one hand, the mechanical engineer must be sufficiently conversant with electronics and computers to integrate them in the various components and systems; on the other hand, the electronics engineer and computer scientist must know enough mechanical engineering to understand the function of the electronic controls.

As these three examples suggest, many analysts argue more generally that *new computer-based technologies, combined with changes in the nature of global competition, are driving rapid changes in production and the organization of work that will demand much more skill, motivation, and involvement at all levels of the work force and will require a revolution in education both for those entering the work force and for those who will be displaced from their jobs* (Adler, 1984; Hirschhorn, 1984; Noyelle, 1987).

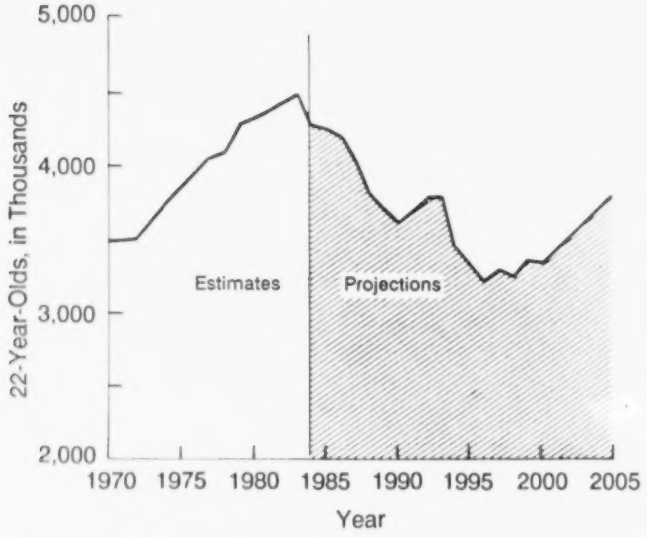

FIGURE 1 22-year-olds in U.S. population, estimates and projections, 1970-2005. Source: Department of Commerce, Bureau of the Census, Projections of the Population of the United States by Age, Sex, and Race, 1983 to 2080; Current Population Reports Series P-25. No. 952 and Preliminary Estimates of the Population by Age, Sex, and Race, 1970 to 1981; Current Population Reports Series P-25, No. 917.

3. The changing talent pool

The stock of engineering talent largely depends on the initial flow of students into engineering schools and on their successful completion of both undergraduate and graduate programs. Although there are many examples from the past that illustrate the flexibility and adaptability of engineering labor markets, there are also serious reasons for concern (Government-University-Industry Research Roundtable, 1987; National Research Council, 1988a).

The number of 22-year-olds in the United States is projected to drop more than 25 percent before the end of this century (Figure 1). Unless a greater proportion of the undergraduate population is attracted to engineering and natural science fields, the best pool for engineers and technologists will decline in size (Figure 2). There is further reason for concern because of the concentration of major engineering colleges in states that will have declines in college-age population that are greater than the national average (American Society for Engineering Education, 1988). Alongside these basic demographic trends is the reported recent drop (Figure 3) in the proportion of freshman identifying engineering as a career preference (Astin, 1987).

Moreover, the fraction of Blacks, Hispanics, and women in high school graduating classes is increasing, and they are traditionally less likely than other groups to pursue careers in engineering and science. The potential for participation of Blacks, Hispanics, and native Americans in the engineering

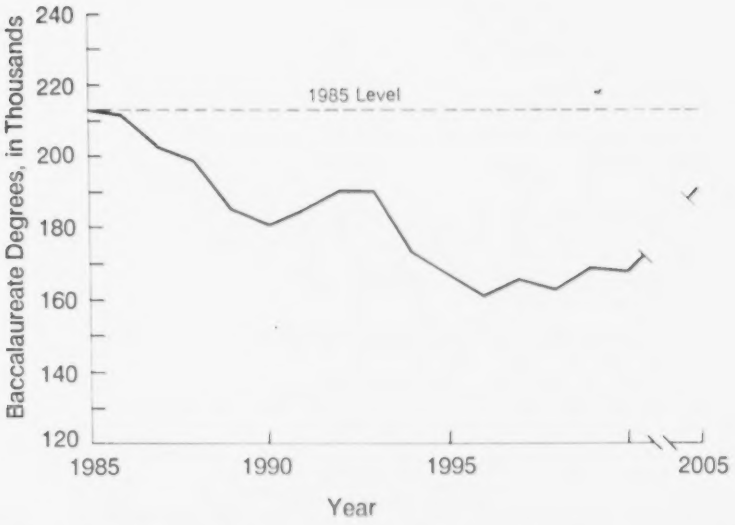

FIGURE 2 Future natural science and engineering baccalaureates, assuming continuation of current (1985) degree attainment rates. Source: Bureau of the Census, Department of Commerce; National Science Foundation; and National Center for Education Statistics, Department of Education.

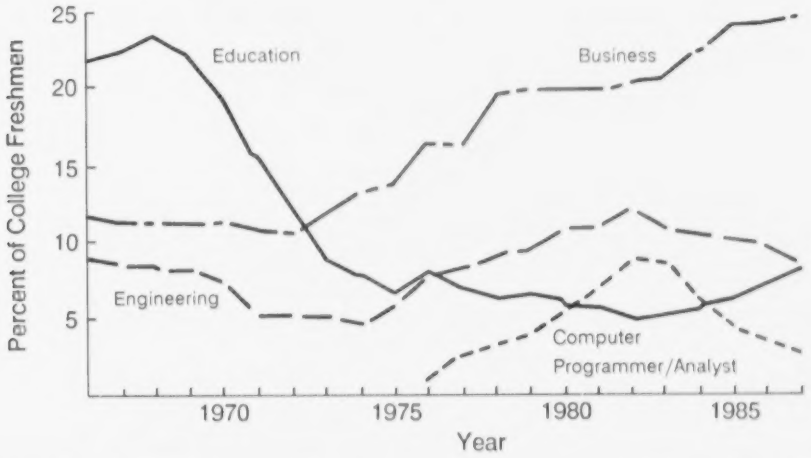

FIGURE 3 Career preferences of college freshmen, in percentages, 1966-1987. Source: Astin, 1987.

profession remains largely untapped. These minorities are greatly underrepresented in the pool of engineering applicants and have, among engineering students, a higher-than-average attrition rate. The participation of women both in the engineering profession and in engineering studies, even with the promising increases of the recent past, still falls short of the potential

levels of involvement. One impediment appears to be the low participation of women students in the study of mathematics and science in secondary schools. Because progress in attracting women and minorities to engineering careers is likely to be slow, depending as it does in large part on the quality of K-12 education, making better use of the current work force may be not only desirable but indispensable for coming decades.

4. The precollege situation

The ability of the U.S. public education system to respond to needs for a technically sophisticated work force is in serious question. There is evidence that American public education is employing fewer and less qualified science and mathematics teachers at the very time when more are needed (National Research Council, 1988b). Many students are taking less and less mathematics and science of progressively lessened rigor at a time when the careers they envision and the nation require that they have more. By grade 10, it is estimated that four-fifths of students are already lost to the engineering and science pool (Government-University-Industry Research Roundtable, 1987). The decline in content and standards in elementary and secondary schools in science, mathematics, foreign languages, and communication skills may now begin to result in matriculation to college of students who are simply not prepared for engineering study, even if they have a preference for it.

5. Needs and opportunities for engineers

Even as the future supply of domestic engineering talent appears to be in question, engineering employment and the demand for engineers are at high and sometimes record levels. The pervasiveness of technology and the skills brought to many kinds of jobs by people with good training in engineering are opening new fields of opportunity for engineers, not only in such traditional areas as heavy industry and public works, but increasingly in the services industries. At the same time, many foreign-born engineers come to the United States, and this pool of talented and motivated people is clearly meeting a significant need (National Research Council, 1988c). However, many foreign-born engineers, not being citizens, are not hired by the government and also are a limited source of talent for corporations heavily involved with government contracts.

Although many engineers continue throughout their careers to be engaged primarily in engineering and applied science, many also increasingly combine this analytical base with several other functions, including the following (Cranch, 1987):

- Managing human resources, leading and working effectively with others in a business environment;
- Evaluating markets, assessing product lines on a national and global basis;

- Allocating financial resources, assessing investments in capital needs, human capital, and business opportunities;
- Adapting to societal and regulatory constraints, interfacing with legal and social realities, appreciating other cultures and political systems; and
- Interpreting technology to the nonspecialist and public sector.

Career-long education for engineers must address both the specialized needs for the practice of engineering and the knowledge needed for more nontechnical, interdisciplinary activities required in the full duration of an engineering career. The latter areas of knowledge almost inevitably cannot be covered adequately in college, and for many engineers the only way to obtain the expanded expertise is through career-long education.

In short, post-baccalaureate, career-long education becomes more deeply necessary with each passing year and must become a better understood, appropriately shared responsibility of engineers, employers, universities, government, technical societies, and other groups. To make this happen, it is critical that all engineers come to the clear realization that their professional growth and productivity are their personal responsibility. Maintaining productivity where it exists and establishing ways to promote its development where it does not exist justify a major national commitment.

3

Intellectual Capital

Sustained success at meeting national objectives and objectives in the world market will depend in large part on the total U.S. capital investment, where "capital" includes not only physical, natural, and financial resources but human and intellectual resources as well. This Committee believes that in today's world, investment in intellectual capital is an option with the highest return. Intellectual capital is like every other form of capital. It appreciates and depreciates, becomes obsolete, requires maintenance, repair, replacement, and modernization. New infusions are required from time to time; venture capitalists are needed; new sources must be sought, and existing sources must be expanded.

The link between education and productivity and other gains is difficult in general to certify definitively and quantitatively. The translation of educational gains into productivity gains is not guaranteed (Kazis, 1988). There are weaknesses of methodology, data, and theory in existing models and research about the link between education and productivity. However, much economic analysis, beginning with the literature that seeks to account for economic growth and extending through human capital theory, does make a credible case for a positive relationship between educational attainment and productivity. The literature also shows that education helps workers adapt to technological change. Cross-national studies show that differently structured systems of education and training can either extend or constrain the range of productivity-enhancing choices available to firms. Similarly, different systems of transition to work and of work organization can enhance or limit optimal deployment of personnel within a firm, in an industry, or across a national economy.

Findings of studies in the specific area of engineering education are

encouraging. Numerous studies have found that increased education and training yield significant gains:

- The 1985 National Research Council report *Continuing Education of Engineers* includes a unanimous finding that education exerts a positive influence on innovation (National Research Council, 1985a).
- Motorola study: Quality engineering education produced a 30:1 payoff in revenue in the same year (Edward Bates, Motorola Internal Report, personal communication, 1987; Galagan, 1986).
- Motorola study: Statistical Quality control course produced a 29:1 payoff in reduced costs of repair and rework in the same year (Edward Bates, Motorola Internal Report, personal communication, 1987; Galagan, 1986).
- A report cited in a National Research Council study (1985b) indicates productivity improvement of 30 to 40 percent resulting from the introduction of computer-aided engineering design.
- A study cited in the journal of the American Society for Training and Development (Training and Development Journal, 1986) showed that "after adjusting for inflation, the productivity returns to on-the-job training was 12.6 percent for those with college education and 19 percent for those without college."
- A study at AT&T Bell Laboratories (Hoover, 1987) shows a fivefold increase in the productivity of the design engineering staff on circuit board designs over a period of 10 years due to application of training and CAD facilities.

Appendix A contains Charles W. Hoover's illustrative analysis of gains that a firm might expect to realize from investment in career-long education for engineers based on moderate assumptions about the effectiveness of such investments. Although Hoover's model is admittedly simplistic, in general the positive financial effects are large in relation to the uncertainties. Certainly it appears that for many employers, investment in career-long education for engineers will compare favorably with other opportunities available for expenditure of resources.

It would be unreasonable to expect that such large increases as those cited above could be attained consistently over a much-expanded national effort. However, the Committee does not believe that the United States is near the limit of possible achievement for the nation's engineering community as a whole.

It is important to understand that the existing work force will be upgraded or replaced only gradually, and that changes in education and training institutions and their output affect a small percentage of the work force at any given time. As Kazis (1988) argues, reforms in education and training are an investment, not a remedial tonic. But it is precisely this long-term view of education that must be more deeply inculcated in and institutionalized for engineers in the United States.

Management is responsible for the development and deployment of all

capital resources, including intellectual capital, used in operating an enterprise. The U.S. record in managing intellectual capital can be improved, both in individual companies and organizations and on a national basis. The Committee agrees with many other groups that the United States will benefit from a continuous expansion of its intellectual capital across the broad spectrum from research scientists, to professional engineers and managers, to technicians and to a skilled work force and an informed population. *The Committee also believes that engineering intellectual capital probably has the highest economic denomination of all forms of intellectual capital.*

4

Benefits to Engineers

Benefits from an expanded and improved national effort in career-long education of engineers will accrue not only to the nation and employers but to engineers themselves. Improvements in engineering productivity generally result in direct financial benefits for firms, and many companies pay bonuses or team awards for increased productivity related to attaining or exceeding corporate goals. Payments of 4 to 5 percent of salary are common in such cases.

Several studies in engineering have reported on the extent to which earnings are a function of formal and informal training on the job (Training and Development Journal, 1986). Individuals tend to leverage their incomes by translating formal and informal learning on the job into higher wages. The best jobs are those that incorporate the most learning. Access to jobs with a high training and development content is a key determinant of lifetime economic success. It is also possible to distinguish relative benefits resulting from informal and formal programs. As stated in an internal report of Motorola Inc., "An analysis of 1983 census data shows that those who have received informal training on their job improved their earnings by 5% more than those who did not receive the training. Those who received formal training improved their earnings by 13% more than their peers" (Edward Bates, personal communication, 1987).

Beyond the direct effects on pay and advancement, engineers may derive additional benefits from career-long education:

- Ability to contribute more effectively on the job and increase job satisfaction;
- Ability to assume more interesting assignments;
- Increased job security;

- Ability to change jobs if a better job opportunity becomes available, if the company fails, or if spouse needs to change jobs; and
- Increased control over personal financial situation.

Clearly, incentives for individual engineers to participate in career-long education are significant. Strong motivation is needed, however. The MIT report (1982) defined precisely the principal hurdle practicing engineers must overcome to pursue career-long education:

> Formal study is hard for anyone at any time, but it becomes noticeably harder with age, when one's mind is preoccupied with other matters. It can also be frustrating and discouraging.

However, there are also encouraging findings about the ability and will of adults to learn. These findings are described in Appendix B.

5

The Current Situation and Its Origins

The United States has a more diverse and dispersed set of institutions for education and training of engineers than most of its industrial competitors. The strengths of this pluralistic system are that it encourages experimentation and tends to minimize large errors. At the same time, it may more readily permit underinvestment when a national need arises. It also makes it more difficult to perceive engineering education as an integrated and continuous system.

When we think of education, we tend overwhelmingly to think of degree-oriented education on campus. Degree-oriented education is formal and structured. It consists of courses and programs that are usually accredited through exact procedures and for which the student receives a recognized credential for participation. It typically has a strong theoretical base and much weaker interaction with engineering practice. Offerings emphasize a spectrum of degree programs (baccalaureates, masters, and doctorates) but also enable students with no degree goals to take single courses or groupings of courses. Degree-oriented programs are offered by a range of providers including colleges, universities, junior and community colleges, proprietary schools, technical institutes, and corporations.

Undergraduate degree-oriented education is one of the greatest strengths of the engineering education system. A positive factor in the U.S. scene is the technical proficiency and skills of current and recent engineering graduates produced by undergraduate programs. A recent National Research Council report (1985b) found "a widespread opinion within industry that the competence of recently graduated engineers is higher than ever before." The report continued: "There is no evidence of a serious flaw in the basic technical education of entry-level engineers. On the contrary, the new engineers have strong analytical skills and an excellent theoretical base in engineering

science." Undergraduate engineering education tends to be characterized by information flow from the faculty to the students, highly structured curricula under strict control, little interaction with practicing engineers, and little direct feedback from the employers of engineers.

It is worth noting that prevailing attitudes among new graduates and among those who have entered the work force in recent years predispose young engineers favorably toward responding to needs that this report addresses. The Committee characterizes some of these attitudes as follows:

- "Don't just let it happen"—taking strong personal responsibility and appropriate actions to maintain and increase health, fitness, and financial security;
- "Innovation for a profit"—interest in the business soundness and financial success of firms as motivation to work for company goals;
- "Questioning"—respect for reason and knowledge, not simply authority, and willingness to question policies and practices;
- "Teamwork"—increasingly introduced as part of the campus experience, familiarity with working on teams.

Clearly, such attitudes among new entrants to the engineering work force are consistent with the goals of career-long education and professional development.

For today's engineering profession, completion of the baccalaureate degree is insufficient to ensure career-long productivity or competence. Changes are needed, both to enhance further the predisposition of young engineers toward continuous professional development and to create stronger and more explicit systems for career-long education to which engineers can readily connect after completing their formal university-based training, regardless of geographical location, organizational affiliation, or degree-level attained.

Before presenting options for the strengthening of career-long education for engineers in the United States it is helpful to review the evolution of the present situation (see pp. 24-25). The following discussion focuses on engineers in industry, because that is where most engineers work (see Table 1). The committee recognizes that there are also other key pools of engineers, for example, engineering faculties, and engineers employed by the military and in public works. The basic message to all groups is the same: There is need for joint commitment by individual engineers and employers to anticipate, adapt to, and influence the changing setting for engineering practice. Part 2 of this report addresses recommendations to all groups.

Career-long education is practice-oriented for redirection, professional self-improvement, updating, upgrading, broadening, and enhancing depth or breadth. The major providers in the arena of career-long education for engineers are company-supported programs (usually restricted to their own employees), the professional societies, the engineering schools, private educational providers, and the government. The National Research Council

Evolution of Corporate Education Programs

Industry has a strong tradition of educating its work force.* In the early days of the industrial revolution, the United States needed to develop a work force in sufficient numbers to operate the factories springing up in the eastern states. The United States was a nation of farmers and craftsmen, not mechanics and engineers, and the apprentice system, then the common method for learning a trade, was inadequate and impractical because large numbers of trained individuals were needed.

Entire self-contained communities were built around the factories and included stores, classrooms and lecture halls, playing fields, gymnasiums, and churches. In short, these communities provided numerous amenities that offered opportunity for self-improvement and enhanced the work environment that provided employment. The employer generally paid for all of these services, and both the company and the employee reaped the benefits.

But the services were not just lofty exercises in benevolence and self-improvement; they were an absolute necessity for employers in the absence of a broadly effective system of public education. Industry education programs of the mid-1800s and the turn of the century provided education for a purpose, namely, productivity; whatever benefits accrued to the individual were incidental. As machines became more and more sophisticated, reeducation of employees was necessary to keep them as "finely-tuned and up-to-date as the machinery" (Eurich, 1985, p. 34).

What began as industry's response to the real, practical need for a large pool of technically skilled labor to operate machinery blossomed into what Eurich describes as a national obsession with industrial progress. Not only were corporate leaders committed to investing large sums of money in technical education and training, an insurance policy protecting the large capital investment already made in a valuable resource, but public and private interest in schools and higher education skyrocketed. A major force entered when Congress passed the Morrill Land Grant College Act in 1862, which encouraged states to establish colleges to train students in scientific farming, engineering, and military science. More than 70 state colleges and universities were established. The land-grant schools have in many instances metamorphosed into the nation's leading engineering universities.

The advent of World War I accelerated the need for a national commitment to industrial and vocational education, and in 1917 the Smith-Hughes Act legislated federal dollars for public education programs in industrial arts and in agricultural and domestic sciences. In 1944 Congress again responded to the national need for a highly trained work force competent in many fields with the GI Bill of Rights legislation that gave returning veterans a stipend and paid for books and tuition at colleges and universities.

---

* This discussion of the history of corporate in-house education programs is derived from Eurich (1985).

In the tradition of the industrial community's past response to changes, and as the best judge of their own needs, some industry firms and sectors have rallied to meet the renewed challenge for technical education, assisted by innovative individuals and groups in academe and elsewhere. The financial cost to firms is considerable, and it is one that may continue to accelerate as companies increasingly have to pay the cost of remedial education of employees as well as continuous technical education and training of engineers.

A growing proportion of education courses that industry offers its personnel are courses to correct for some of the deficiencies in the formal education system. This trend puts an additional strain on industry's education and training departments, on university and private providers of career-long education, and on the nation's collective financial and intellectual resources, since industry's primary concern is to provide opportunity for employees to gain value-added knowledge that enhances performance skills. Remediation does not foster innovation and creativity, it plugs educational gaps with essentials that might be more appropriately offered in preparation for—or as part of—an earlier curriculum. How long industries will assume this responsibility, even though it is in their own best interests to do so, is unknown.

The history of the development of today's modern corporate classroom in large companies traces a philosophy of focused assessment of, and attention to, needs and goals, dedicated commitment to educating employees to improve productivity, and development of talented in-house technical people for promotion to middle- and upper-management positions. Faced with a shortage of trained technical personnel after World War II, industrial firms could either wait for the public education system to channel appropriately skilled and knowledgeable individuals to the workplace in numbers sufficient to meet their needs, or they could do it themselves. Again, their past successes and the need to act quickly encouraged them to implement comprehensive large-scale education programs, designing them once again with efficiency, productivity, and skill-building in mind.

Some corporate classrooms excelled at providing technical education for specific industries, and these schools developed into respected academic institutions in their own right with accredited degree programs. Northrop Corporation's industry aircraft school, for example, became Northrop University, which offers various degrees in engineering, business administration, and management. General Motors' night school that began in 1926 grew to G.M.I. Engineering and Management Institute and offers a range of degrees in engineering and in industrial and manufacturing management.

Industry's investment in education continues; the need for programs of career-long education for the engineering work force has prompted corporate America to invest billions of dollars in technical education. It is estimated by the American Society For Training and Development that industry spends $30 billion to $60 billion annually on formal education and training programs; if wages for time spent learning were included, the figures could double. The capacity of U.S. institutions to respond has been demonstrated: the need is to respond in a more coordinated, sustained manner.

TABLE 1A Employment Profile of Engineers and Computer Specialists by Field and Type of Employer, 1986.

		Business/Industry		Educational Institutions		Federal Government	
	Number	Number	%	Number	%	Number	%
Total Engineers	2,244,000	1,791,000	80	91,000	4	181,000	8
Engineers by Field							
Aeronautical/ Astronautical	104,000	77,000	74	4,000	4	18,000	17
Chemical	132,000	114,000	86	5,000	4	7,000	5
Civil	319,000	196,000	61	9,000	3	32,000	10
Electrical/ Electronics	541,000	440,000	81	25,000	5	53,000	10
Mechanical	454,000	394,000	87	17,000	4	29,000	6
Other engineers	694,000	570,000	82	32,000	5	44,000	6
Computer Specialists	437,000	341,000	78	33,000	8	32,000	7
Total Engineers & Computer Specialists	2,681,000	2,132,000	80	124,000	5	213,000	8

SOURCE: National Science Board, 1988, appendix table 3-5
NOTE: Detail may not add to total because of rounding. A fourth category for other types of employers is not given.

Committee on the Education and Utilization of the Engineer (NRC, 1985a) provided a profile of career-long education for engineers in the United States. All such education, as far as industry is concerned, relates in some way to improving productivity. Except for the professional societies and the National Technological University, most providers offer courses in their own geographical area, using their own facilities.

Programs to keep engineers current in the latest technologies are alive and well in many U.S. companies, especially larger ones. Some other kinds of employers, like the uniformed services of the military, have also evolved sophisticated programs for the continuous technical development of their personnel. A great number of possibilities exist, including on-the-job experience and training, job-rotation, cooperative education programs with universities, summer internships, and special leaves of absence. Many companies that have a long history of providing education for their employees provide good examples of what to do and how to do it. However, the overall national picture is patchy, with participation varying substantially according to size and location of employer and other factors. Table 2 shows that 65 percent of engineers employed in small, nonurban firms did not participate in continuing education in a given year.

A wide variety of educational opportunities are made available through seminars, short courses, conferences, colloquia, interactive video and computer programs, and various other delivery systems. Industry also spends a significant amount of money on full-tuition reimbursement and material support for engineers enrolled in degree programs. In 1986, more than 68,000 engineers enrolled in part-time degree programs, many of them paid for by their employers. The current educational opportunities that are available to individuals as members of a corporate community—at little or no direct financial cost to them—are often ample. Career-long education is seldom a

TABLE 1B Primary Work Activity of Engineers & Computer Specialists, 1986

		Research		Developm't		Mgmt. of Developm't		Mgmt. Other Than Developm't		Teaching		Product'n & Inspct'n		Statistical Work and Computing	
	Number	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Total Engineers	2,244,000	99,000	4	681,000	30	227,000	10	419,000	19	53,000	2	398,000	18	109,000	5
Engineers by Field															
Aeronautical/ Astronautical	104,000	10,000	10	40,000	38	21,000	20	9,000	9	2,000	2	11,000	11	6,000	6
Chemical	132,000	8,000	6	42,000	32	18,000	14	24,000	18	3,000	2	20,000	15	5,000	4
Civil	319,000	7,000	2	44,000	14	10,000	3	103,000	32	6,000	2	70,000	22	14,000	4
Electrical/ Electronics	541,000	27,000	5	210,000	39	77,000	14	75,000	14	13,000	2	81,000	15	23,000	4
Mechanical	454,000	17,000	4	187,000	41	48,000	11	80,000	18	9,000	2	67,000	15	12,000	3
Other engineers	694,000	30,000	4	158,000	23	53,000	8	127,000	18	20,000	3	149,000	21	50,000	7
Computer Specialists	437,000	14,000	3	87,000	20	27,000	6	36,000	8	16,000	4	15,000	3	206,000	47
Total Engineers & Computer Specialists	2,681,000	113,000	4	768,000	29	254,000	9	455,000	17	69,000	3	413,000	15	315,000	12

SOURCE: National Science Board, 1988, appendix table 3-4
NOTE: Detail may not add to total because of rounding. A seventh category for other types of work activity is not given.

TABLE 2 Percentage of Engineers Who Participated in Continuing Education Over One Year

Type of Continuing Education	Large Urban Firms (N = 144)	Small Nonurban Firms (N = 177)
Advanced degree-related courses	29.9	--
Other degree credit courses	13.9	4.5
Noncredit courses		
Conducted at firm	7.6	1.1
Conducted away from firm	18.8	6.8
Other educational activities		
Conducted at firm	13.9	7.9
Conducted away from firm	25.7	29.4
Leaves with pay	2.0	--
Organized self-study	7.6	7.3
Other	2.8	--
All types combined	63.9	35.0

SOURCES: Levy and Newman (1979), Welling et al. (1980).

condition of employment from the employer's view, although it has become a major recruiting tool of those companies who are competing for the best students nationwide.

Although hundreds of thousands of engineers receive formal or informal training every year, the negative side of this statistic is that the number of engineers in industry who are motivated to learn the new technologies and take advantage of the programs made available by their employers may be much lower than the cost of education programs suggests and company training directors like to admit.

The National Research Council report *Continuing Education of Engineers* explored this issue in depth, identifying the reasons some industry engineers give for not participating in education programs. In order of importance, those reasons are as follows: prohibitive amounts of travel time required to get to class, inconvenient class meeting times, personal commitments, lack of encouragement from supervisors, lack of perceived need or payoff, lack of encouragement from the company, and insufficient financial support from the company.

In response to the complaint about distance and travel time, some companies have established linkages with universities that offer various M.S. degree programs through television, and they receive regular on-campus instruction, both live, delayed, and by videotape broadcast. Some companies also are willing to offer in-house courses on a time-sharing basis whenever possible. Special conferences, seminars, and short-courses, though theoretically valued and perceived as beneficial, are more difficult to schedule on a regular basis, and because they interrupt the engineer's schedule, which is pressured by deadlines, they are often more difficult to implement.

Three of the reasons engineers give for not participating (lack of perceived need, lack of payoff, and lack of company encouragement) reflect a point of view that is opposite to what management *says* is true, namely, that keeping current with new developments through educational activities is vital to the engineer's career and to the company's growth. Either management is remiss in its efforts to support career-long education with a suitable infrastructure that links corporate philosophy with corporate practice, or the engineer's perception of the company is wrong, or, more likely, some combination of the two.

What concerns industry the most is not necessarily the money it spends on education and training, but whether it is getting the best return on the investment. Thus, the questions for industry are, how to bring more engineers into the classroom, how to get a higher percentage to complete courses, and how to coordinate programs for the "just-in-time" delivery of knowledge and skills needed to do the job. In essence, the question is how to optimize the value of education to the company.

Some companies may have problems matching corporate philosophy—"the training of our technical staff is important, and vital to our future" with actual in-house practice. A few large companies, believing that capital spent in improving the talents of their engineers is a sound business investment, have designed noteworthy programs that can serve as models for others to emulate. At other companies, the question of whether or not to have an education program is asked year by year, and the response—or lack of it—is tied directly to that year's profitability; in other words, there is little system at all, more "reaction" to what is perceived to be a pressing need. *A well-designed company infrastructure that encourages, supports, and sustains a policy of career-long education from the highest corporate level through the managers and supervisors to the line engineer is essential.* It is the most likely guarantor that a program will be able to interest, enroll, and retain the number of engineers needed to make it cost-effective and successful.

Companies need to work on communicating the right message to employees. Companies may have sound ideas about the importance of career-long education, but their internal support for education programs may be less than efficient. If education budgets are the first to be reduced or cut entirely when company profits are down, companies project the message that education is expendable. And if employees who participate in career-long education are not given opportunities to compete for better job assignments, particularly assignments that make use of the new knowledge gained, they begin to question the reason they are devoting personal time and energy to the pursuit of new knowledge. Some companies handle continuing education as if it were a "bandage," something to affix to a problem as it surfaces in the hopes that it will go away. The myth is that all a company needs to do is to bring in some courses, establish some training programs, send a few top-notch performers to the nearby university to obtain a master's degree at company expense, and those engineers will show marked improvement at the workbench, productivity will increase, and so will profits. The problem

with such an approach is that it lacks structure, supervisor support and encouragement, definite goals, the commitment of upper-level management, and long-term funding. Such an approach treats the symptoms, not the disease; in the long run its chances for success are limited.

The philosophy of education at some large companies that have provided corporate training programs for years has begun to take a more decidedly practical approach. Rather than fret over the issue of motivating more people to participate, some companies now concentrate their energies on improving the clarity of their message. That message is essentially that the company provides various opportunities for engineers to improve their skills and advance in their careers. Those who take advantage of these opportunities will get more challenging assignments, will become more flexible, will be better contributors. Those who do not keep themselves current, with the company's help or on their own, will be at a decided disadvantage. The message is, "It's your choice; it's your responsibility."

6

A Technological Opportunity

The national and individual needs for career-long education for engineers are matched in an exciting way with opportunities provided by new technology. Advances in information technology are providing new tools for educators in developing cost-effective responses to the challenges of providing accessibility to career-long education.

Available information technologies can be grouped into eight categories: audio (voice), video, computer, imaging, copying, storage, networking, and technologies for metering usage and cost. These information technologies expand the accessibility of improved, individualized higher education through the creation of increasingly varied assortments of communication networks interconnecting specific client groups.

These networks consist of a set of nodes interconnected by a series of transmission links. Nodes can include any kind or combination of end sets—telephones, computer terminals, video displays, workstations, copiers, facsimile devices—any device that will interface the user with the network. Nodes may also serve as switches to other networks or as gateways to yet other networks.

Almost every major educational organization has put various elements of the available information technologies into place to meet the increasingly complex needs of engineering education. Some universities such as Carnegie Mellon and MIT, have made major efforts in computer usage and networking. Others, such as the University of Pittsburgh, have made significant efforts in installing campuswide integrated information systems that include audio, video, and data communications. Others, such as the Illinois Institute of Technology and the state university system of Florida, have made major commitments to television systems. Indeed, almost every major metropolitan area in the United States is served by an engineering college through

nstructional television, fixed service (ITFS). Others, such as the University of Arizona, Colorado State University, and Georgia Institute of Technology, have fundamental strengths in videotaped education.

There are several consortia of universities united by common interests and commitments to the use of information technologies in career-long engineering education. The first to make significant use of video technologies was the Association for Media-Based Continuing Engineering Education (AMCEE), which provides videotaped continuing education courses from its member universities; course delivery may be by cassette or by satellite. The National Technological University, a consortium of universities that are a subset of the AMCEE membership, has taken on the satellite delivery responsibility while also providing degree programs in engineering using the same G-Star 1 satellite. There are also the many information networks—some specialized to computers such as BITNET, ARPANET, and CSNET, to name just a few. Other networks, such as INTELENET, are statewide, and others, such as OCLC, serve libraries. Many educational institutions are also using PLATO and other information technologies in the teaching process. Gradually emerging is a coordinated application of all available information technologies at individual institutions, creating a functional model of what may be the university of the future, the "televersity" (Martin, 1987). It will have the general characteristics shown in Figure 4. Televersities could deliver cost-effective, individualized, higher or career-long engineering education of improved quality to traditional university students as well as to students previously excluded because of distance, employment, location, or physical or other handicaps.

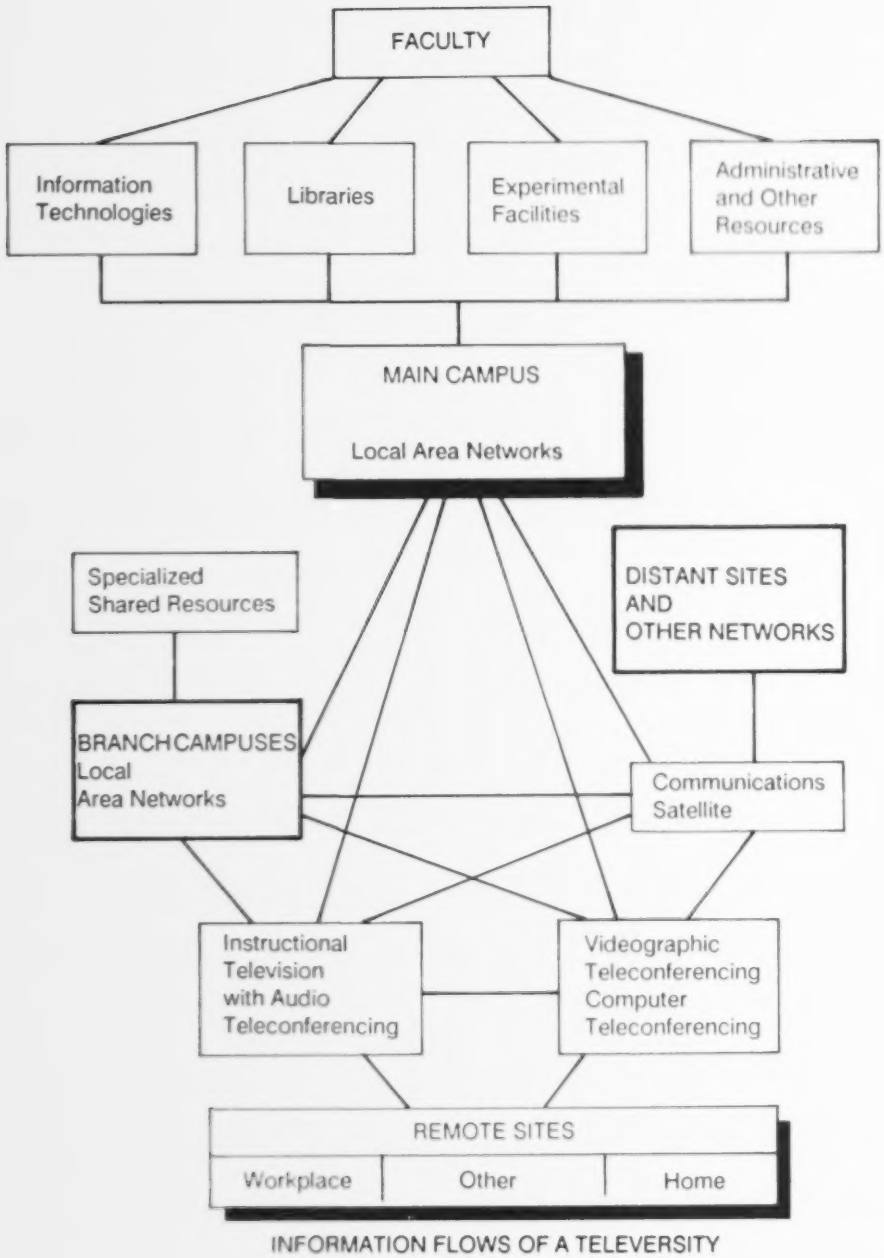

FIGURE 4 Flows of information in an idealized televersity.

7

The Structural Problem and the Need

Given the needs for, and the likely benefits of, programs of improved career-long education for engineers, it is necessary to explain why the situation has not yet taken care of itself. The answer lies largely in a structural system in which costs and benefits are not always closely tied to one another either in space or time. There is no doubt that career-long education of engineers is beneficial to society as a whole. However, it is not clear that individual employers that finance this education for their employees benefit directly from it. In view of the high mobility of engineers, often those engineers whose education has been funded most generously are the ones who leave their employer, sometimes to go to work for a competitor. At least on a short-term basis, it may appear more economical for employers to eliminate the cost of career-long education and to hire engineers who have the required knowledge as they need them.

Unfortunately, the history of American business shows that not all employers who have invested generously in the career-long education of their employees have prospered. Some companies that have reportedly shunned career-long education have done well financially. The central difficulty is that, as long as engineers are free to change employment, there is no guarantee that the employer who pays for career development is going to reap the benefits.

For different but parallel reasons, not all engineers who devote extra effort to obtain additional education derive benefit from it. Employers tend to reward tangible accomplishments. Thus, a given amount of effort by an engineer may well produce quicker and larger benefits when it is devoted to current engineering tasks, such as design or process development. Benefits of career-long education (and the penalties for the lack of such education) typically accrue after, sometimes long after, the effort to obtain the education

has been expended. As a result, the connection between the education and the benefits are often not recognized by the employee.

The way out of this trap is through a much broadened appreciation by the nation, employers, and individual engineers that career-long education has become a necessity for the U.S. engineering enterprise as a whole. There is a need for everyone to understand better the system for engineering education as an integrated whole and the place of career-long education in it (Figures 5 and 6). In focusing on its future, the engineering profession must promote a shared vision of a new pattern of education.

A gulf exists in engineering education today. We have a highly organized and effective system of degree-oriented education and a sporadically effective, sometimes outstanding, sometimes unresponsive, and often murky set of elements that address education needs that begin when a student leaves degree-oriented programs.

Many actions by many groups, some actions taken collectively and some individually, can enhance the engineering intellectual capital of the United States. The National Action Plan presented in Part 2 of this report provides courses of action that the Committee urges individual engineers and all organizations in the engineering community to consider. Although the Committee can offer no sweeping solution to the problems addressed in this report, leadership by the engineering community as a whole can ensure a range of actions that can in the future substantially improve national productivity, the utilization of the engineer, and the fulfillment of individual career goals.

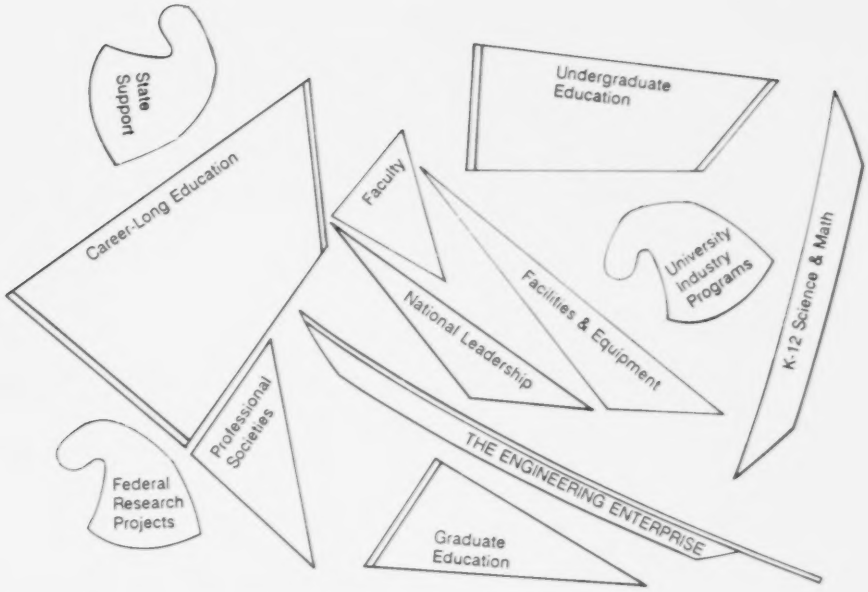

FIGURE 5 Elements of the system of engineering education.

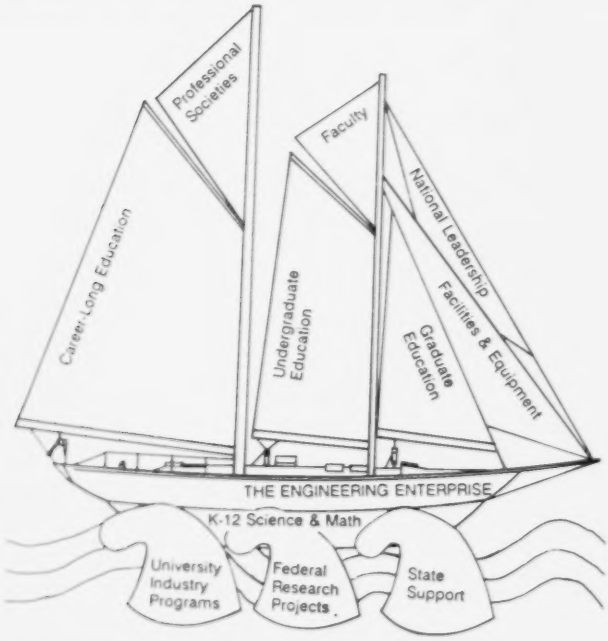

FIGURE 6 Engineering education as an integrated system.

Part 2

A National Action Plan for Career-Long Education for Engineers

A National Action Plan for Career-Long Education for Engineers

A national action plan for career-long education for engineers addresses action items to the engineering community in the following areas:

1. The need for a nationwide coalition;
2. The need for a systems approach;
3. The need for employer support of education objectives;
4. The need to broaden the mission of educational institutions;
5. The need for government action to foster career-long education; and
6. The need for increased leadership from professional societies and other groups.

1. The Need for a Nationwide Coalition

There is a vacuum at the national level in the engineering community where there should be active and sustained leadership guiding and supporting career-long education for engineers, although significant effort and leadership in individual engineering disciplines exist largely as a result of engineering professional society programs. No institution or group of individuals, no government agency or industrial association, takes as its mission the critical role of advocacy and enhancement of career-long education across all engineering fields and for interdisciplinary areas. No single organization acts with broad and comprehensive effect as a central source of information about career-long education or performs the function of informing and motivating engineers. The establishment of a nationwide coalition to coordinate, monitor, urge, and advocate action is essential, in the view of the Committee, to advance career-long education. The coalition would explicitly guide a nationwide effort for promotion of career-long education in the national interest and that of employers and individual engineers.

The coalition should include representatives from industry, academia, professional societies, government agencies concerned with technology and education, private providers of career-long education for engineers, and others knowledgeable in the area. It has the difficult but essential task of moving from the present patchwork of educational programs offered for practicing engineers by employers, universities, for-profit vendors, professional societies, and others towards systems that have a recognizable framework. Elements of such systems exist, but the essentially decentralized nature of the U.S. higher educational and industrial enterprise requires that a coalition be formed so that the current players can develop systems with enough coherence to provide the needed services more effectively to practicing engineers, whether employed in industry, government, or academia.

This coalition can best be launched by a disinterested, knowledgeable group that has credibility throughout the entire engineering community. Although the engineering professional societies currently offer educational services, no single society has the breadth of mission nor the ability to mobilize the industrial, governmental, foundation, and individual support needed to bring the coalition into being. It is here that the National Academy of Engineering (NAE) might play a crucial, if nontraditional, role. If requested by the other elements of the engineering community, the NAE should be willing to serve as the initiating organization to catalyze the overall community actions needed. Actions will be necessary to form the initial coalition, specify its functions, and mobilize the essential support and endorsement of industrial, educational, governmental, and foundation leaders.

The need for a nationwide effort in career-long education was clearly identified by the MIT report on lifelong learning in 1982. It was reemphasized in the 1985 NRC study on education and utilization of the engineer, and in other reports since that time. The Committee believes that the time for action on the part of the engineering community is now.

The nationwide coalition could become the engine powering and sustaining improved performance of systems for career-long education. The coalition should address the following issues:

- Identification of professional or subject areas where special nationwide efforts for career-long education for engineers may be needed or deficiencies exist;
- Anticipation of future needs;
- Ways to enhance delivery of educational services;
- Identification of approaches that work;
- Increased recognition of the benefits of career-long education for engineers;
- Encouragement of cooperation between various sectors and groups;
- Models for assessing the value and quality of programs;
- Tax and regulatory issues; and
- Recognition of academic achievement and transfer systems for academic credits.

In effect, this new nationwide coalition would provide impetus for the implementation of many other recommendations contained in this report. Over a period of time, its leadership would give greater visibility, credibility, and weight to benefits from sound programs for the career-long education of engineers. The specific form of the coalition, its administrative support and location, should be debated and resolved by the engineering community, especially the professional societies. Funding for sustaining such an undertaking should be of interest to government agencies and industry.

2. The Need for a Systems Approach

The engineering community as a whole must exercise leadership in communicating that engineering education is an *integrated system*, clarify the desired characteristics of the career-long portion of the system, and improve the accessibility and other features of career-long education.

A combination of factors, including intense international economic competition and the complexity of changes in the workplace brought by new technologies, requires more from engineers than talent and a college degree. These requisites are the basics one needs merely to begin the practice of engineering; they have become the foundation that provides entry to the marketplace. At the current rate of technological advance they are not sufficient to guarantee even a hard-working engineer the expertise needed for a productive and challenging lifelong career.

Career-long education for engineers takes over when initial, formal education ends, usually at the completion of a degree program, whether baccalaureate, master's, or doctoral. Taking a "systems" approach—seeing engineering education as an interactive and interdependent process that forms a unified whole with past education and work in progress—naturally includes on-the-job training as an integral part of the process, just as additional courses of instruction, formal or informal, build on previously acquired knowledge and current experience.

The career-long portion of the overall engineering education system should be designed and developed to do the following things:

- Enable engineers to connect with it readily regardless of geographical location, organizational affiliation, or degree level attained.
- Bring high-quality programs to those engineering communities that are not served to any significant degree by current efforts, such as engineers employed by small companies, on foreign assignment, in remote locations in the United States, and those whose low income inhibits participation.
- Be adaptable to the professional needs of the engineer as perceived by the individual or the employer throughout the engineer's active professional career.
- Make efficient use of the time individuals can devote to it.

- Be adaptable to the individual engineer's job requirements so that education services are available at times and locations compatible with other professional and personal requirements.
- Be affordable, such that the beneficiaries, primarily the employers and the individual engineers are willing to bear most of the costs.
- Employ pedagogical techniques that minimize student frustration.
- Provide access to other individuals as mentors so that students can gain strategic advice and help in defining reasonable goals and estimating requirements.
- Make available subject matter so that practicing engineers can
  - undertake development of technical capability in a technical area different from the one undertaken during earlier phases of their career;
  - learn about new developments in the technical areas in which they work; and
  - gain new skills of both a technical and a nontechnical nature to meet changing job requirements.
- Provide both educational and training services and make available "hands-on" experience at convenient locations when essential.
- make Use of new information and computing technologies.
- Respond rapidly to new engineering and science developments so that updating can be accomplished in a timely fashion.
- Provide engineers with more permanent and portable records of completed educational activities to help enhance the engineer's career options and professional status and inform present and future employers about employee accomplishments.
- Emphasize institutional accessibility in space (minimum or zero travel time), time (convenience of class schedules in days and hours), cost (methods and convenience of payment), administrative resources (advising, general information, scheduling, registering, paying of bills), learning resources (faculty, library, computers, laboratories), and support services (parking, food services, bookstore, study facilities, recreation, storage lockers).

3. The Need for Employer Support of Education Objectives

All private companies and other organizations that employ engineers, including governmental agencies and not-for-profit institutions, should clarify and focus their educational objectives by linking those objectives with their overall goals. In particular, they should take the following action:

- Adopt as policy the idea that those who keep current and productive and those that consistently improve their performance are positioned to compete for the best and most challenging job assignments.
- Make it clear that the technical competence of the staff is highly valued, and be sure that a system is in place to give that philosophy credibility.

- Emphasize that the maintenance of engineering quality is a cost-effective investment by the employer.
- Maximize the effectiveness of available internal and external education programs by improving the organization's support mechanisms and policies for stimulating continuing education for its engineers.
- Design infrastructures that encourage, support, and sustain a policy of career-long education, from the highest level of the enterprise through line managers and supervisors to the industrial engineers.
- Implement education programs (both internal and external) that correspond to the objective of keeping engineers current.
- Become more aware of the characteristics of engineering professionals; learn to identify those barriers that discourage participation in education activities; create strategies to dissolve those barriers.
- Reassess the structure and activity of the in-house training offices to encourage a cooperative and productive dynamic between the human resource staff that puts programs together and the engineers for whom programs are designed.
- Communicate clearly the educational expectations they have of their employees during the recruitment process, at the point of hiring, and during orientation.
- Require their managers to maintain education practices that are in accord with the organization's overall education philosophies.
- Include as part of the performance review and reward structure for managers, evaluation of how effectively managers encourage and support the educational development of the engineers they supervise.
- Expand the increasingly widespread practice of an annual review of educational aims and objectives of technical personnel.

Appendixes B (pp. 65-67) and C discuss additional ways for employers to enhance their programs for career-long education for engineers.

4. The Need to Broaden the Mission of Educational Institutions

Engineering schools should reassess their role as professional schools with regard to the educational demands that the advances in new technologies place upon the B.S. engineering professional and should include the career-long education of engineers as part of their mission.

Engineering schools can respond effectively to the education needs of engineering professionals as well as to those of conventional, full-time students. Some schools have in fact added career-long education programs to their mission of research, teaching, and public service. Significant contributions have been made by schools that schedule seminars for the local industrial community and provide readily accessible master's degree programs for engineers employed part time in industry. The Committee recommends that such current outreach efforts continue and that other creative links be forged to meet the current and growing need for career-long education. A variety of

possibilities are available on campus to upgrade the status and effectiveness of career-long education for engineers.

At the outset engineering schools should make a concerted effort to impart to undergraduate and graduate students the desire for career-long education. They should take the following actions:

- Emphasize the importance of career-long education and professional growth, beginning at the freshmen level and continuing through the senior and graduate years, and invite and encourage discussion of engineering as a profession.
- Provide career counseling, educational resources, and faculty members in the roles of mentors to support the idea that career-long education is both personally valuable and a career necessity.
- Make it clear that engineering and engineering-related jobs are of great variety and various degrees of complexity; that engineering comprises many related parts that make up a whole; that engineers who educate themselves to recognize, appreciate, and be knowledgeable about the various dependent, interdependent, and synergistic elements of the knowledge base are those best able to contribute to their profession. These are the individuals who are able to take optimum advantage of the various opportunities for growth and development that will enhance their careers, add to their flexibility, improve their performance, and prepare them for a challenging and exciting future.
- Teach engineers how and when to evaluate where they are in their educational evolution, how to ask the right questions of themselves and others to determine what they know and what they need to learn, and how and where to locate and obtain the new knowledge needed.

Engineering schools should also consider the following options:

- Develop more flexible provisions for the transfer of earned academic credits when an engineer enrolled in an accredited degree program is transferred to a different geographic location (see note 1).
- Strengthen the relationship they have with their extension units, from rewriting the rules that might limit faculty participation to offering financial assistance or staff support to experimental programs that help defray operating expenses (see note 2).
- Increase incentives for faculty to teach in career-long education programs.
- Expand the sharing of videotaped programs and courses with other schools in cooperative brokering of the best programs (see note 3).
- Encourage deans and department chairmen to take the initiative in developing the budget and organizational resources necessary to support the continuing professional development of every member of their faculty.
- Consider increasing education services of colleges of engineering to alumni through career counseling, retreats, special seminars, access

to classes available by alternative delivery modes, short courses, conferences, or freedom to enroll in on-campus classes as space permits (see note 4).

- Encourage universities to continue to admit part-time industrially employed engineers into engineering school master's programs (see note 5).
- Encourage universities that have television capabilities to develop resources to provide an expanding menu of master's degree programs to those industry students that meet the university's criteria for enrollment, adjusting residency requirements as needed (see note 6).

5. The Need for Government Action to Foster Career-Long Education

The federal government and state governments should recognize the growing importance of career-long education for engineers and begin to assume more responsibility for it, taking appropriate action to foster improvement of programs and facilitate participation.

The National Science Foundation (NSF) is the federal agency with the core responsibility for basic research in engineering and for engineering education. Consistent with a systems view of engineering education, this mission should include not only K-12, undergraduate, and graduate education but career-long education as well. In particular, the Committee recommends that the NSF take the following steps:

- Support experimental programs in career-long education for practicing engineers; such programs might serve as models or prototypes, for example:
  - innovative programs using computer and television technologies or other alternative delivery systems that can reach large numbers of engineers and remotely located engineers (see note 7);
  - programs involving consortia of schools that are willing to share educational assets to explore new curricula and programs focused on rapidly advancing or neglected areas of technology.
- Expand support for programs in career-long education and development for faculty members of engineering schools in both research universities and teaching-oriented colleges.
- Support research about career-long education for engineers; such a program might include data collection, study of effects on individual engineers, research with regard to adult learning in engineering and technology to improve design and efficiency of programs, and evaluation research on programs in use in the engineering community (see note 8).
- Include in future volumes of *Science and Engineering Indicators* data and analyses related to career-long education for engineers, in order to
  - provide information on numbers of engineers participating in various kinds of programs and costs of such programs;

- review data on career-long education programs in various companies; analyze effects of education on job mobility, promotion rates, research outputs, and career flexibility; assess company retention rates of engineers who actively pursue career-long education; and assess aspects of productivity change in companies where career-long education programs are well defined.

Tax rules can have a high leverage in affecting choices by both individuals and firms with regard to their investment in education. The Committee recommends that Congress review carefully the potential effects of changes in tax laws on participation in, and availability of, career-long education for engineers.

Several states, like Michigan, have exciting, experimental programs to make use of their educational assets for career-long education. Such programs should be encouraged. In some states, policies relating to funding may be reducing the role that universities could play in career-long education for engineers. The Committee recommends that state legislatures and state universities examine pertinent rules to encourage participation of full-time faculty members as well as experts from industry acting as adjunct faculty members in career-long education programs.

6. The Need for Increased Leadership from Professional Societies and Other Groups

Engineering professional societies and other independent groups should assume an even stronger leadership role in the outreach to individual engineers. Engineering professional societies have thrived because they provide needed services to their members. They are logical candidates to assume an even stronger leadership role in the outreach effort to engineers, "championing" the importance of career-long education to the individual. They are well positioned to do the following:

- Identify skills and knowledge needed to develop competency and suggest study plans in the various areas of expertise represented by their members.
- Design appropriate tests for self-assessment and measurement of levels of proficiency.
- Establish guidelines for standards when these are needed and share such guidelines with educational providers.
- Conduct and disseminate reviews of programs and provide information on, and recognition for, successful programs.
- Provide their members and others with resource directories of who has what and how it can be obtained, including information about regional and nationwide programs, private provider services, and so forth.

- Explore establishing, perhaps on a communitywide basis, national on-line data bases that would provide information about availability of engineering education courses, seminars, and special programs.
- Further their efforts to support engineers in start-up and small firms and small industries and in isolated areas.
- Increase understanding of the interdisciplinary nature of many new and advanced technologies.
- Provide Recognition through awards and other means to individuals and groups who have made outstanding contributions to career-long education for engineers.

Career-long education has benefited from innovative efforts by a range of private providers, organized on both a nonprofit and a for-profit basis. In an area as diverse and dynamic as engineering, the flexible and rapid responses of such groups have special value. The Committee urges preservation of the atmosphere that allows such institutional innovation, combined with increased attention to quality assessment criteria and evaluation information that can be widely shared with the engineer.

Notes

1. Transfer of credit hours for the engineering professional: schools can group together, and each group can agree to accept credit hours for transfer, inter alia. The entrenched practice of accepting only 6 credit hours for transfer disinclines many working professionals from attempting to earn an advanced degree, because it is common practice for many engineering firms to move engineers to different locations at frequent intervals.
2. Support extension units: Many universities have established extension branches of their engineering schools to serve the educational needs of the industrial community. Over the years, some of these extension units have prospered and many have merely endured. Some colleges of engineering have only a minimal relationship with their extension bureaus and provide them with little or no financial or faculty support. The heavy demands of running external programs that are expected to be self-supporting often inhibits the effectiveness of extension programs. There are also rules and regulations that limit a faculty member's compensation for participating in such programs, with the result that few of the most talented faculty members get involved.
3. Brokering of courses produced by other vendors could help answer the faculty shortage problem faced by some schools, particularly in departments of electrical engineering and computer science. Videotaped courses would extend the outreach of faculty experts nationwide, not only enriching the curriculum of on-campus students but meeting regional industry needs that broker schools may be unable to meet in any other way. For a successful brokering agreement, a quid pro quo to the

professor teaching the videotaped course and some benefit to his or her institution or department are assumed.

4. Special education rates and programs for alumni: Some schools allow alumni to take courses without enrolling in a degree program. They are able to obtain an official transcript of each course they take and they are also given a tuition break. Those schools that find a way to support the continuing education of their own alumni can reap the benefits that accrue when alumni perceive school loyalty as a two-way street; gift-giving to one's alma mater becomes a practical investment in one's own future, as well as an expression of gratitude for four years of undergraduate instruction.
5. Part-time industry students in master's degree programs: Many public and private universities have responded to the educational needs of local industries and are admitting part-time industry students into master's degree programs; this advanced formal education is one valuable kind of "career-long" education. Schools can set up special sections that are scheduled for hours most attractive to industry students, use television as a delivery medium, or assign faculty members to teach a section at the workplace. Industry cooperates by allowing employees flextime schedules or short-hour days, on-site tutors, proctors, and advisers. In addition, they frequently provide co-op sponsorship to on-campus students and adjunct faculty to the university.
6. Using television technologies to deliver master's degree programs to industry: Television can save time in commuting and thus lower barriers for both the engineer and the employer to participation in educational programs. Interactive television in real time that allows for two-way communication has been in use for nearly 25 years and can now be set up by microwave, phone, fiberoptic, or satellite connection. More than 15 years of experience with the Tutored Videotape Instruction mode shows that this is an efficient and cost-effective way to deliver graduate instruction on-site in appropriate circumstances.
7. Because there are approximately 2.7 million engineers and computer specialists employed in engineering-related activities, education programs that have the potential to reach large numbers of engineers need to be encouraged. The potential number of participants that can be served by satellite television technologies is enormous. For example: Texas Instruments offered a 5-hour seminar on artificial intelligence in the fall of 1987. This program was broadcast to 1,200 sites worldwide and was viewed by 65,000 engineers. At the present time, universities and a large number of companies have television capabilities; most of these schools offer master's degrees in various engineering disciplines by television.
8. Although much has been said about the need for career-long education of engineers, little *scholarly research* has been done in recent years to substantiate quantitatively many of the hypotheses and conclusions drawn from the anecdotal information culled from the surveys and questionnaires of individual companies and experienced as truth by those

working in the field. One reason for the lack of hard data and rigorous analysis is that there has been little or no financial support for research in continuing education in engineering or any other profession.

References

Adler, Paul. 1984. Rethinking the Skill Requirements of New Technologies. Working Paper HBS 84-27. Graduate School of Business, Harvard University, Cambridge, Mass.

American Society for Engineering Education. 1988. Report of Task Force on Student Pipeline to the Engineering Deans Council. Washington, D.C.: American Society for Engineering Education.

Astin, Alexander W. 1987. The American Freshman: National Norms for Fall 1987. American Council on Education and the Higher Education Research Institute of the University of California, Los Angeles.

Cranch, Edmund T. 1987. Continuing engineering education in the United States: An overview and assessment. Engineering Education 77(7-8):657-668.

Eurich, Nell P. 1985. Corporate Classrooms: The Learning Business. Princeton, N.J.: Carnegie Foundation for the Advancement of Teaching.

Galagan, Patricia. 1986. Focus on results at Motorola. Training and Development, Journal May:43-46.

Government-University-Industry Research Roundtable (GUIRR). 1987. Nurturing Science and Engineering Talent. GUIRR, National Academy of Sciences, National Academy of Engineering, Institute of Medicine. Washington, D.C.

Hirschhorn, Lawrence. 1984. Beyond Mechanization. Cambridge, Mass.: MIT Press.

Hoover, Charles W., Jr. 1987. AT&T Technical Journal, July-Aug 1987.

Kazis, Richard. 1988. The relationship between education and productivity: Implications for the competitiveness of American manufacturing and the movement for educational reform. Massachusetts Institute of Technology, Department of Political Science. Cambridge, Mass. January.

Levy, G. W., and S. C. Newman. 1979. A Survey of Continuing Education for Nonacademic Scientists and Engineers. Columbus, Ohio: Battelle Columbus Laboratories.

Martin, Thomas L., Jr. 1987. The televersity: The university of the future. Industry and Higher Education. Surrey, England. September.

Massachusetts Institute of Technology, Department of Electrical Engineering and Computer Science. 1982. Lifelong Cooperative Education: Report of the Centennial Study Committee. Cambridge, Mass. October 2.

National Academy of Engineering. 1988. The Technological Dimensions of International Competitiveness. Washington, D.C.: National Academy of Engineering.

National Commission on Excellence in Education. 1983. A Nation at Risk: The Imperative for Educational Reform. Washington, D.C.: U.S. Government Printing Office.

National Research Council. 1985a. Continuing Education of Engineers. Committee on the Education and Utilization of the Engineer, Panel on Continuing Education, Morris A. Steinberg, chairman. Washington, D.C.: National Academy Press.

National Research Council. 1985b. Engineering Education and Practice in the United States: Foundations of Our Techno-Economic Future. Committee on the Education and Utilization of the Engineer, Jerrier A. Haddad, chairman. Washington, D.C.: National Academy Press.

National Research Council. 1988a. The Effects on Quality of Adjustments in Engineering Labor Markets. Committee to Study Engineering Labor-Market Adjustments, Office of Scientific and Engineering Personnel, Harrison Shull, chairman. Washington, D.C.: National Academy Press.

National Research Council. 1988b. Improving Indicators of the Quality of Science and Mathematics Education in Grades K-12. Committee on Indicators of Precollege Science and Mathematics Education. Washington, D.C.: National Academy Press.

National Research Council. 1988c. Foreign and Foreign-Born Engineers in the United States: Infusing Talent, Raising Issues. Committee on the International Exchange and Movement of Engineers, Office of Scientific and Engineering Personnel, Stanford S. Penner, chairman. Washington, D.C.: National Academy Press.

National Science Board. 1988. Science and Engineering Indicators—1987. Washington, D.C.: National Science Foundation.

National University Continuing Education Assocation (NUCEA). 1987. Challenges for Continuing Higher Education Leadership: Corporate/Campus Collaboration. Washington, D.C.: NUCEA.

Noyelle, Thierry. 1987. Beyond Industrial Dualism. New York: Westview Press.

Training and Development Journal. January 1986, p. 233.

Welling, L. G., G. W. Levy, and S. C. Newman. 1980. Survey of Continuing Education Delivery Systems for Scientists and Engineers Employed in Small, Non-Urban Establishments. Columbus, Ohio: Battelle Columbus Laboratories.

Appendix A

Return on Investment in Career-Long Engineering Education

CHARLES W. HOOVER, JR.

How much should a company invest in the continuing education of its engineers? What is the return on incremental investment in education compared with other investments a firm can make? Should a company reallocate its budget to increase the funding for education? This paper provides a quantitative approach that can help decide these questions.

If explicit data on the effects of education on engineering productivity can be obtained for a firm, we could analyze these data in relation to the firm's financial assumptions and other factors to find the return on investment in education. Because there is little generally applicable information of this type, however, a different approach has been adopted in this paper to show the limits of affordability for education. Rather than attempting from the outset to assess the relationship between productivity and educational investment, we can assume an increase in productivity and find how much the firm could afford to pay for education that produces the assumed increase. We assume that the increase in productivity produced is small in relation to the total engineering effort* and that the firm can invest the increased engineering effort made available (typically 10%) in ways that produce at least its usual rate of return. We can also assume that there is no "released time" for education, so that the added costs are for courses and other instruction outside of working hours. Investment in education increases engineering productivity only after a period of time, and this increased effort, invested in development projects, produces increased net income after a further delay.

*The small perturbation case is chosen for two reasons: First, this makes the calculation more realistic in that significant additional capital and marketing investment would not be required. Second, several high-payoff opportunities are available in many companies today (for example, quality improvement and the implementation of just-in-time manufacturing) that require only small additional engineering efforts.

Thus, this analysis takes into account delays and the time value of money. The analysis can be particularized for a given firm or industry segment by appropriate choice of financial parameters. The process is as follows:

- Assume an increase in engineering productivity, produced in a specified time.
- Find the incremental net income produced in the firm by the application of this additional effort at its "going rate."
- Find the amount of the break-even educational investment stream by setting, at an appropriate discount rate, present worth (PW) of the (educational investment stream) equal to the present worth of (incremental net income from productivity increase).

The financial performance of the firm is described by three factors: the firm's cost of money or discount rate (r), the development interval (DI), and the development factor (DF), which is defined as the ratio of the present worth of incremental gross margin to the present worth of development expense at a given discount rate. The development interval is defined as the time between investment in development for a typical project and the realization of the net income from the project.

For the small perturbation case, significant capital investment is not required, and the ratio of debt to equity is not changed. Thus, to a good approximation, incremental net income can be equated to incremental gross margin.

Figure A-1 shows schematically the education investment stream, the resulting productivity gain, and net income. Figure A-2 shows the break-even educational expense for a 10 percent productivity increase for a typical high-tech firm operating with a DF = 4, a development interval of 2 years, and an education "start-up" time of 1 year, for two discount rates. The study period was 10 years, and results are quite insensitive to variation to 8 years. A development factor of 4 is reasonable for a high-tech firm in light of an analysis of data from 42 Profit Impact of Management Strategy (PIMS) businesses by the Strategic Planning Institute (Ravenscraft and Scherer, 1982). This analysis shows that a "profit" of $3.08 was obtained in 1978 from R&D expenditures of $1 spread over the years 1972-1975. Results of parametric variations of DF and DI about the point shown circled in Figure A-2 are given in Table A-1.

The canonical target for investment in engineering expense for education is 2 percent. Companies such as AT&T, Exxon, and IBM all spend more than 1.5 percent, and Motorola requires that 1.5 percent of their development budgets flow to education. The 2 percent level is sometimes mentioned as paying for one week of education per year, an amount many analysts believe is the minimum required to obtain a positive result.

For a typical high-tech firm operating with the parameters given, we find that a firm could afford to invest much more than the canonical 2 percent to get a 10 percent productivity increase. In an ideal situation, a firm would

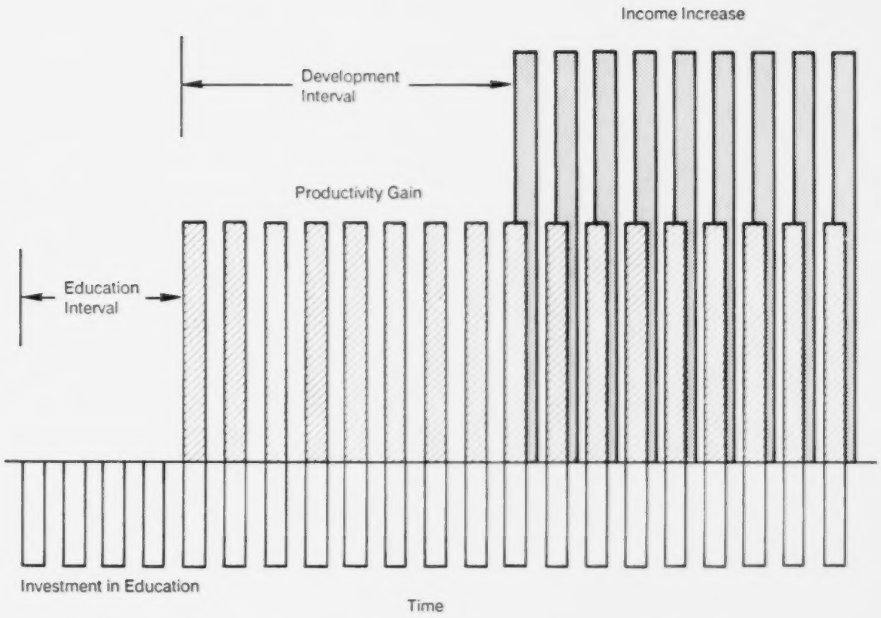

FIGURE A-1 Return on investment in education (shown as cash flows).

initiate or increase its education, track the effect, and optimize its investment in education along with its other investments.

If 10 percent productivity improvement is produced by an investment of less than the break-even amount, the investment will have a positive return on investment. To see how good such investments might be, we have calculated the internal rate of return (IRR) for various cases, again using the financial assumptions cited above. Table A-2 shows the IRR for education that produces 10 percent productivity improvement at the stated levels of investment, assuming no released time.

As noted, we have assumed that the engineers continue to work full time as they are educated, that is, there is no released time. This is typical of what is done in many companies today and is a reasonable assumption for relatively small incremental investment levels. This assumption is less reasonable for large increases in education spending.

Released Time Case

We now analyze the important case where the firm releases time for education. In other words, engineers spend a fraction of their standard workweek in "in-hours" study. Here, we assume that the total engineering expense budget remains constant and find the break-even amount of released time. In this case, we have set the education expense equal to the engineering salaries for the time devoted to education, since these salaries constitute

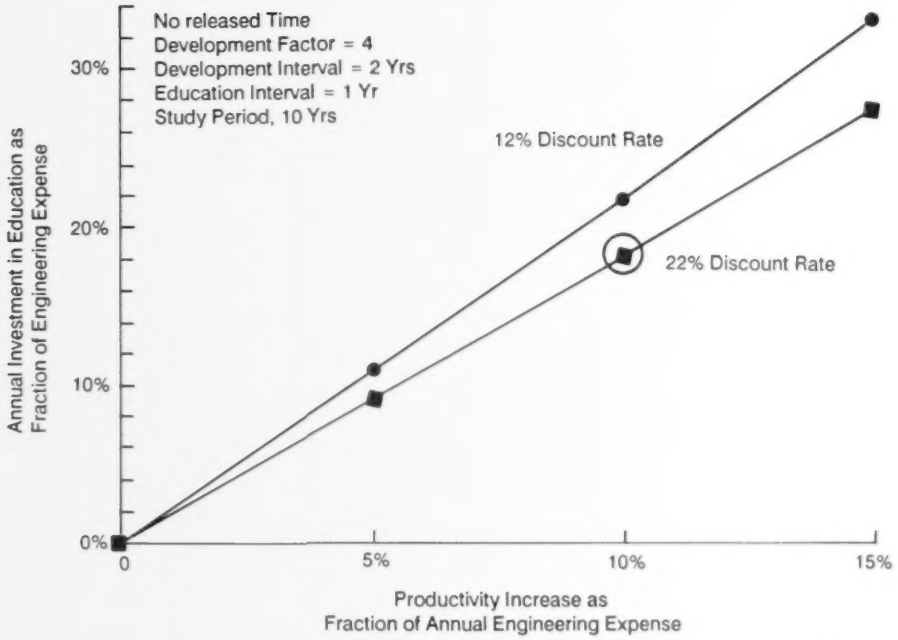

FIGURE A-2 Break-even educational investment (for stated productivity increase).

TABLE A-1 Break-Even Educational Expense for 10% Productivity Increase as a Percent of Annual Engineering Expense
Discount Rate 22%, 10-Year Study Period

Development Factor	Development Interval, years* 1	2	3
2	12.4%	9.6%	7.3%
4	24.8%	19.2%	14.6%
6	37.2%	28.8%	21.9%

*after 1-year education start-up

TABLE A-2

Education Investment as % of Engr. Salaries	IRR %
5	95
10	57
15	35

most of the cost. If a portion of the standard workweek is devoted to education and the total effort remains constant, productivity is initially reduced and this decreases total gross margin downstream until it is offset by the productivity increase produced by education. Moreover, the total effort available for projects is reduced by in-hours time spent in education. For these reasons, time released from regular work hours for education is expensive.

The break-even amount of released time for an education program that leads to a 10 percent improvement in productivity at the end of 2 years is 5.7 percent (or about 3 weeks per year) for a firm with r = 22 percent and DF = 4. This corresponds to 120 hours per year, or about four standard two-credit-hour courses.

Discussion

Many companies can probably afford to invest more than the typical 2 percent of their engineering budget in education with profit, and somewhat larger released-time programs than are common may also be affordable.

The large difference in break-even cost between out-of-hours and in-hours programs suggests that firms might profit by making it attractive for their engineers to take courses out-of-hours, even to the extent of paying them for such time.

These analyses assume that the stream of investment in education that is started up or incremented continues indefinitely. In the long term, this continuous investment would certainly help to keep engineers productive. However, these analyses have not included such long-term benefits.

This analysis could be extended in various ways. For example, using continuous discounting rather that discrete cash flows, it would be possible to calculate the time at which the net present value of the benefit crosses over the net present cost of the education investment and produces a positive return on investment. For the assumptions used above, crossover times of about 4 or 5 years might be expected. It would also be possible to relate the development factor to specific criteria for project selection, such as time to break even or rates of return.

The results suggest that it would be highly desirable to close the loop to find explicitly the benefits of increased engineering education. This might be done through studies within particular firms or more broadly through an organization such as that which operates the PIMS data base.

This study has purposely made use of moderate assumptions with the intention of producing results that apply broadly across corporate America. Although the percentage improvement productivity sought (10%) is small, it would produce an increment of engineering effort equal to about 3 year's output from the engineering schools. There may be no better practical way in coming decades to obtain such a large increment in U.S. engineering intellectual capital.

Reference

Ravenscraft, D., and R. M. Scherer, 1982. Is R&D Profitable? PIMSLETTER No.29. The Strategic Planning Institute, Cambridge, Mass.

Appendix B

Adult Learning and the Engineer

PAMELA H. ATKINSON

The problems of motivating practicing engineers to pursue career-long education are a special subset of the problems of adult learning. The following discussion considers first the characteristics of adult learners that distinguish them from younger students and, second, the results of recent research related to adult learning.

Characteristics of Adult Learners

Adult learners are distinguished from younger students by differences in the number and diversity of their responsibilities, choices, attitudes, and experiences. Adults are characterized by the ways they perceive time, the various roles they assume, the number of personal and professional relationships, the ability to analyze needs and set priorities, and their ability to pursue long-term goals (Smith, 1982).

The responsibilities adults assume are a critical determinant of how they use their time and establish their priorities. Whereas students are primarily self-obligated and focused on attaining immediate goals, such as finishing a particular course, getting a summer job, saving money for graduate school, or relaxing with friends on the weekend, adults' interaction with the world around them is much broader. They assume more complex roles; they are spouses, parents, concerned adult children of aging parents, members of professional and community associations, civic leaders, and maintainers of homes; they are also friends, colleagues, and mentors of other adults. Like students, adults also believe that time spent alone or in recreation with friends is an important part of life.

Adults have lived through a great many kinds of experiences that contribute to their knowledge of life and inform their judgment when they make choices. They are able to internalize and evaluate various goals, assessing

the relative value of instant versus delayed gratification. They are willing to set long-term goals and work patiently to attain them.

As the maturing process continues, adults develop a more relaxed attitude, find ways to put things in perspective, and learn not to take themselves too seriously. Many develop a comfortable acceptance of not only their strengths but also their limitations. Ideally, mature adults learn to distinguish the real limitations that might put some goals beyond their reach from limitations that are self-imposed or imagined.

As adult responsibilities and commitments increase, their lives become more complicated and unpredictable. Unforeseen changes that interrupt familiar and comfortable patterns of living bring about anxiety and indecision. These feelings add to the stress caused by the situations themselves, which creates more stress and exacerbates feelings of inadequacy and helplessness.

Adults need to have a sense of control over their lives, and they find it hard to organize and plan for the future when certainty about the future evaporates. Most adults are able to marshal their internal resources and apply the wisdom they have acquired over a number of years to help them through periods of transition and negotiate periods of crisis.

For some adults, the idea of acquiring new knowledge, particularly if it is needed for career enhancement, is formidable. Intellectually, they accept the fact that they will be better off for it and agree that the new knowledge and skills they gain are highly marketable career benefits. Paradoxically, adults will find reasons to justify their inability to participate in the very programs they have come to understand they need. Perhaps the most insightful bit of information adults can learn about themselves is to understand that such a conflict of desires is not at all uncommon, and, once understood, can be resolved.

Internal conflict is created when a person is strongly committed to two ideas that are inherently in opposition to one another. One such conflict is caused by an adult's strong need for stabilty and the equally strong desire to change in ways that will benefit them. This particular conflict of opposites creates a tension that is difficult to resolve. "When adult learners have too little autonomy, their dignity can be affronted, their motivation inhibited, and their pleasure in learning stifled. But learners suddenly confronted with more responsibility for their own learning than they expected or are used to usually respond with anxiety and sometimes withdrawal" (Smith, 1982).

Adults will find it easier to accept the concept of education as a lifelong pursuit if they explore the idea of a time continuum that is spiral. The idea that time is linear, that activity appropriate to one stage of life is appropriate *only* to that stage can bind an individual to choices made in the past. And an adult's sense that present time is "too late" may be closely linked to feelings of anxiety about the ability to perform well in the present because the "normal" time to pursue learning is while young. As Smith observes, " 'I am too old', and 'If I were twenty years younger' may be ways in which the adult is not only talking about his chronological age but also stating what he feels about his own capacity." Smith also suggests that some mature adults

may perceive whatever time is left to them as something precious, perhaps even to be "hoarded, not spent."

Past emphasis on high achievement creates fear in the present. The emphasis that schools place on individual achievement is particularly significant for adults when they consider earning advanced degrees. The fear imposed by old memories of test-taking places more stress on them when test-taking is required in the present than it does on their younger counterparts. Some adults may delay applications to graduate school simply because they believe they will not do well on the Graduate Record Examination.

Emphasis on individual achievement also hinders the teamwork approach that is necessary in almost all work environments. The emphasis that primary, secondary, and undergraduate education places on working alone to achieve good grades makes it difficult for individuals to learn to work in teams, an ability highly prized by companies that employ engineers. Although collaborative teamwork is the approach most favored by many engineering companies, the reward system that is generally in place recognizes the exceptional merit of individual achievement, not the achievement of teams.

There are other barriers that keep adults from continuing their education. Many individuals find it difficult to reconcile the conflict between meeting their own needs and responding to the needs of the other significant people in their life. Many people believe that self-expression and self-exploration connected to work activities are both valuable pursuits in themselves and vital for mental and emotional health, but a desire to pursue these activities can often assume priority and overshadow the desire to respond to the commonality of needs that are basic to the life and health of the family and the community. Because adults recognize that these other needs are also important, many men and women find that their ambitions and desires vie for priority with their responsibilities and commitments to family, friends, and society. Every conflict adds greater stress to the decision making process, and a greater preponderance of choices makes choosing that much more difficult.

Every society develops its own framework for the right way to do things. Twentieth-century America seems to have accepted the idea that life naturally divides itself into a series of progressive states and stages—childhood, adolescence, and adulthood—each characterized by norms appropriate to that phase. Although the stages overlap, the natural rhythm of the process is a movement forward, from one stage into and through another.

Childhood is a time for play and imaginative daydreaming, for freedom from responsibility, and for physical, mental, and emotional growth. It begins the process of learning how to live in the world, first at home with parents as role models and teachers, then outside the home in the structured environment of school. It is a time marked by total dependence on adults, who are trusted authority figures. Time is not a problem for children; they always have more time than they know what to do with.

Adolescence is a time of choosing and testing, finding one's limits and

accepting them or challenging them. It is a critical stage on the path to maturity, painful and difficult to cross. It is a stage of short duration for some and of endless length for others. Time is not a problem for teenagers; their problem is setting priorities for doing what matters most, based on personal specific needs at the time.

Adulthood is the time for work and the acceptance of responsibility for self and others, of securing the future by saving and investing time and money wisely. Physical health and vitality become an issue at this stage, whereas they are often taken for granted at other stages. The demands of work, personal needs and goals, and relationships with family and friends continually compete for time and attention. The loss of loved ones through death, divorce, or illness adds additional stress, fatigue, and worry. There is a growing awareness of personal mortality. What is comfortable and familiar may become more attractive than what is new, different, and challenging.

Time is critically important to adults and plays a major role in influencing decisions. There is never enough time to do everything; so daily chores, personal and professional commitments, work life, and recreation are carefully plotted in the attempt to balance the basic requirements of life against the needs of the human spirit.

Research Findings on the Adult Learner

A growing body of research has been devoted to the adult learner, particularly in the past 15 years. Various theories of learning have been espoused by educators who have gathered and interpreted data on the educational activity, the behavior, the cognitive functions, the life cycles, and the changing career patterns of working adults in order to understand more about adult learning.

In a recent exploration and critique of some of these theories, Brookfield (1986) cautions researchers that to specify generic principles of learning is an activity full of intellectual pitfalls. Nevertheless he is able to identify common themes highlighted in a number of studies to show that, even though adults "learn in different ways, at different times, for different purposes," researchers generally agree on the following basic premises:

- Individual differences, not chronological age, limit the learning ability of adults.
- Adults seem to be naturally inclined to self-directed learning throughout life.
- Learning is more effective when it takes place in a supportive environment; a nonsupportive environment is stressful, and stress is a major block to learning.
- An individual's ability to exercise some control of the educational process encourages and enhances learning.
- Practice and feedback provide the individual with positive reinforcement and are important to the learning process.

- Past educational experience and self-perception affect the individual's motivation, both positively and negatively.
- The demands of an individual's current personal and professional life often prompt educational activity. Education is most valued when it is meaningful, useful, and applicable to solving the problems those demands create.

Additional theories that have been advanced by Brundage and Mackeracher (1980), James (1983), Kidd (1973), Knox (1977), and Smith (1982) add to the body of knowledge about adult learners and underscore the complexity of the subject. Although the following observations are not verities etched in stone, they are the result of systematic study over several years and are useful ideas to consider when facilitating programs for adult learners:

- The decision to go back to school may startle family and friends who may believe that such activity is totally inappropriate and suspect. The perception others might have about their motives, goals, judgment, and behavior can cause ambivalence and anxiety in adult learners, undermining their confidence and causing them to doubt their own abilities. Mature adults are particularly sensitive to not wanting to appear foolish to others, and they feel threatened when their personal autonomy is diminished or threatened. They often are inhibited by their own high standards of performance and a sense that they might not be able to meet them.
- Adults learn best when learning meets a specific perceived need, when they assume responsibility and take charge of the learning process, and when they can immediately make use of what they have learned.
- Adults often experience their life in transition at 20-year intervals, and are sometimes most responsive to educational offerings that relate to those transitions.
- The demands on an adult's time are often the primary consideration when a decision is made about pursuing any new activity; time is often of greater importance than money spent or effort expended.
- Adults tend to doubt their own ability, overemphasize past inadequacies, and frequently perform beneath their level of competence.
- Some studies show that learning ability is not only retained well into adulthood but may also be increased.
- The ability to set one's own pace will optimize adults' ability to learn; their achievements in their 40's and 50's can reflect the same level of competence they demonstrated when younger; keeping the length of time short between formal education and new learning makes the new learning experience more effective.
- Short-term memory functions well into adulthood; there are also indications that long-term memory improves with age.
- Variations in ability to think critically and creatively when problem-solving relate to individual differences rather than task complexity and show only a marginal relationship to age.

- Whereas the self-concept of a child is one of dependence, the responsibilities, experiences, and achievements of adult life encourage ever-greater degrees of autonomy and confidence, fostering a self-concept of independence.

Most educators of adults believe that self-directed education is the educational process most likely to produce the best long-term results. They are eager to accept the idea that self-direction is a natural characteristic of adulthood and can be sharpened, or that it is at least a characteristic or trait that can be learned. Brookfield believes that research on cognitive function may lead to greater insights in this area, and many educators hope that, as this function is better understood, techniques can be developed to refine it, perhaps even guide its development in children. Educational materials might then be designed to complement this approach and create a "best fit" teaching method to enhance learning at all levels for adults and children alike.

Based on the research to date, Brookfield offers six principles that he and others believe foster successful adult learning:

1. Learning cannot be demanded; to be effective, it must be voluntary.
2. All participants must sense that they are worthy, valued, and deserving of respect; alternative ideas and attitudes may be challenged, but not in a way that denigrates the individual.
3. Facilitators and learners are collaborators; they assess needs, choose goals, and critique results as a group, and "the group process involves a continual renegotiation of activities and priorities in which competing claims are explored, discussed and negotiated"; in this way, the participant "owns" the learning experience and the outcome.
4. Effective learning is a loop, a continuing process of activity, reflection, analysis, and new or renewed activity. Questions and answers, exploration of other points of view, and the linking of participants' experience with new information are all necessary elements of that process.
5. Effective learning inspires individuals to think reflectively about their own experience. It prompts a critical review and analysis of their own cultural conditioning, present situation, personal beliefs, and various other aspects of "personal, professional and political lives."
6. Effective learning encourages adults to become more self-directed learners. This is more than just knowing how and where to find the information they need; more than the ability to improve their skills to meet criteria imposed by another. The self-directed learner becomes more autonomous, imposes his or her own goals, and explores ways to achieve them. "At the heart of self-directedness is the adult's assumption of control over setting education goals and generating personally meaningful evaluative criteria . . . . Adults who . . . reflect critically on their assumptions and try to imagine alternatives are fully autonomous, self-directed learners. Such

adults are likely to be involved in a continual reinterpretation, renegotiation, and re-creation of their personal relationships, work lives, and social structures."

The basic characteristics of the generic "adult learner" also apply to the adult engineering professional. Human resource directors in industry and providers of engineering education need to understand better the variables that govern an adult's life and the complex and multifaceted characteristics of adult learning. The immediacy of educational needs and the urgencies of business do not lend themselves to taking time for this interpretive process. When program development concerns itself solely with content and logistics, the one consideration that might make the difference between a successful or an unsuccessful program—attention to human needs—is often given such low priority that its effect is negligible.

Companies tire of trying to motivate large numbers of engineers into participating in career-long education programs in which they have invested large sums of money. What they prefer is a self-motivated work force, eager to learn and ready to enroll in the wide variety of courses, seminars, and programs that are available. They want their engineers to be excited about learning, thrilled by the acquisition of new knowledge, and ready to make time for it, no matter the personal cost in time and effort.

If a company is committed to the value of career-long education, it is often generous with its financial support and provides a large assortment of educational options. When enrollments drop in various programs, senior management often believes that the problem is lack of motivation. Although that may sometimes be true, it also can occur when there is a weakness in the chain-of-command communication about education and how it serves and supports the company's objectives and goals. Failure to improve this line of communication may be an indication that management is ambivalent about career-long education even while providing for it financially.

Individuals enroll in education programs for a variety of reasons. The reasons that guarantee best results seem to be those that come from the individual's personal conviction that they will be the better for it. *Not* enrolling is harder to decipher, because it can be either a conscious or an unconscious decision.

What keeps engineers from enrolling in education and training programs? *Continuing Education of Engineers* (National Research Council, 1985), a number of company in-house studies, and information gathered in interviews with individual engineers offer these explanations:

- A company's ineffective in-house dissemination of information about educational opportunities can prevent employees from receiving the information they need to make enrollment decisions in a timely way. Course listings tacked on bulletin boards or one copy of the schedule of courses routed to each division manager in the hope that information will reach the segment for which it is intended are poor ways

for a company to advertise courses, yet some do it this way to cut publication and distribution costs.

- Many companies assume that when company policy dictates that education and training is to be encouraged, line managers will support it. The reality is that line managers—even at those companies that have the most successful and the most widely touted education programs—are continually cited as a major reason individuals do not sign up for courses. Managers who say they support education programs but who convey the message that "when you come back, your real work will be waiting for you" are not uncommon. Conversely, a manager's encouragement and support are cited most frequently as a reason individual engineers are motivated to participate in education programs.
- When all courses and seminars must be taken fully or partially on the engineer's own time, this presents a major obstacle to improving individual participation rates. Most engineers routinely put in more than an eight-hour day, and burnout is a reality for a great number of engineering professionals.
- Company rules that require strict adherence to project accounting by time sheets stifle the kind of creative interaction that can vitalize engineers and keep them interested in learning the new technologies that will improve their performance. "Learning from colleagues" is highly valued by most engineers and for some it may be the most viable way to keep themselves informed.

Companies can help their engineers assume more responsibility for their own career-long education. Following are several specific means of providing this help and some real-life examples of success:

1. Involve engineers in the program planning and development of various courses, seminars, and in-house training to bring about personal "ownership" that adult learning activity requires. Honeywell Avionics Systems Group, Clearwater, Florida, involves managers and engineers in program and curriculum planning. Employee ownership of programs results in a 92 percent completion rate.

2. Provide visible leadership. The believability of a company's commitment to career-long education hinges on the visibility and active support of someone highly positioned in the company hierarchy, such as a president or vice president. Creating a vice president for engineering professional development and giving that individual the authority to promote and support the programs that are necessary for the company's survival, including programs to change the company mind-set, make that commitment a reality.

3. Actively encourage managers to take part in career-long education, as participants, tutors, and mentors. Hewlett-Packard Network Measurements Division, Santa Rosa, California, demonstrates the impact when managers are personally involved in education and training. Virtually every manager has been a tutor for Hewlett-Packard's TVI Master's Program televised from

Stanford. Result: every engineer currently enrolled in the program expects to be a tutor in the future because it is the "thing to do."

4. Educate managers in the best ways to encourage the people they supervise. The active involvement of line and project managers in the career-long education of their engineers not only will improve education participation and completion rates but also can help create an internal network of shared resources to benefit the next generation coming through the ranks. Lawrence Livermore Laboratory has developed a fluid matrix system that brings people together from different groups, assigns them to special projects, and gives them the freedom to use each other as "expert resources."

5. Consider work time an appropriate time for education and training. Do not penalize the engineer by requiring three hours of new learning and two to three hours of homework on top of eight hours at the workbench.

6. Provide work assignments that allow the engineer to practice and perfect what he or she has learned as soon as possible.

7. Provide staff support for education and training offices, or coordination in sufficient depth to free the engineer from the time-consuming paperwork of filling out forms, obtaining signatures, tracking down reference materials, book lists, and so forth; the engineer's time is better spent in pursuit of engineering, either at the workplace or in class. Some companies believe that getting the right message to the new employee encourages greater participation in education and training programs. Corning Glass Works, for example, requires newly hired employees to attend an extensive orientation program, modeled on a program designed by Texas Instruments and scheduled over a 12-month period. Result: greater participation in education and training programs, improved retention of new hires, and resulting savings of millions of dollars.

In conclusion, adults need to recognize that continuing their education, either formally or informally, can provide access to goals that are not only desirable but attainable and bring them a great deal of personal satisfaction as well. They need to realize that age does not inhibit the ability to learn, that past failures need not hold them back, and that obstacles and fears can be overcome. To design and operate effective programs in career-long education for engineers, there is a widespread need in the engineering community to appreciate better that which characterizes the experiences of adult learners, what inhibits and discourages the pursuit of new knowledge, and what motivates individuals to continue learning throughout life.

References

Brookfield, Stephen D. 1986. Understanding and Facilitating Adult Learning. San Francisco, California: Jossey-Bass Publishers.

Brundage, D. H., and D. Mackeracher. 1980. Adult Learning Principles and Their Application to Program Planning. Ministry of Education, Toronto, Canada.

James, W. B. 1983. An analysis of perceptions of the practices of adult educators from five different settings. Proceedings of the Adult Education Research Conference, No.24, Concordia University/University of Montreal.

Kidd, J. R. 1973. How Adults Learn. New York: Cambridge Book Co.

Knox, A. B. 1977. Adult Development and Learning: A Handbook on Individual Growth and Competence in the Adult Years. San Francisco, California: Jossey-Bass Publishers.

National Research Council. 1985. Continuing Education of Engineers. Committee on the Education and Utilisation of the Engineer. Washington, D.C.: National Academy Press.

Smith, R. M. 1982. Learning How to Learn. New York: Cambridge Book Co.

Appendix C

Characteristics of a Successful Education Program in a Large or Medium-Size Company

What does the well-designed, vigorously management-supported engineering education program look like? For large and medium-size companies, the ideal model would have the following characteristics:

The successful engineering education program is multifaceted and complex. A variety of in-house seminars and short courses are scheduled regularly, using company experts, university professors, or private consultants. Engineers attend these programs on company time when they are directly related to a job assignment and on a shared-time basis when they are primarily related to career development.

The courses are designed to appeal to an adult learning style, and peer interaction is encouraged through a variety of means, such as peer discussion groups, tutored review, interactive computer programs, and question-and-answer sessions with the experts.

A large number of engineers are enrolled part-time in off-site degree programs at local universities, and a smaller number attend prestigous institutions full-time with a cost-of-living stipend and company-paid scholarships.

Funding for the program is not based on profits or on the discretionary funds of individual managers but is a predetermined percentage of the overhead operating budget and is shared among departments according to size and need.

The operative motto of the program is "let's plan ahead." The company's objectives and goals determine the overall educational objectives, and systematic needs analyses regularly keep the learning objectives of each division on target. Engineers as well as project managers participate in making decisions about what needs to be learned and what level of proficiency should be achieved, and all participants are strongly committed to completion of courses. Job assignments provide immediate opportunity to

put new knowledge and skills to use, and engineers quickly build proficiency in, and eventually attain mastery of, new techniques, processes, systems, and discrete bodies of knowledge.

A core group of engineers and managers assesses current needs and anticipates future ones. They use a comprehensive, up-to-date data base to evaluate courses provided by outside and in-house experts. These records and evaluations from other sources give detailed information and allow the group to choose what best suits their needs from what is available, or choose to have something custom designed.

Time for education and training is built into the work schedule, and education programs are designed to be flexible to adjust to the demands of work assignments when the need arises. This flexibility is understood to work two ways; engineers who work overtime to meet deadlines are given time away from work to make up the instructional hours they missed; homework assignments, of course, are done at home; computer support is provided whenever possible.

A support staff handles the mechanics of enrolling in programs and such related activities as obtaining course information, ordering books, coordinating exams, and arranging consultations with the experts, which frees the engineer to devote time to meeting educational objectives. The size of the support staff that provides this service is large enough to address the program-support needs of all participants.

Publicity for the program and dissemination of enrollment information are comprehensive and reach all potential participants on a timely basis.

There is a cultural ethos that supports and encourages mentoring. Everyone at some phase in a career is in a position to act as a mentor for someone else, and whether giving or receiving, both individuals reap benefits.

Participants in education programs are acknowledged for their achievements and encouraged to continue to set and meet new educational goals. Engineers discuss educational and career goals with managers yearly. Managers are recognized and rewarded as they contribute to development; an active staff-development effort rewards managers favorably, by influencing promotions and merit increases.

Career ladders are established for both management and technical staff. There is opportunity to move back and forth between the two tracks, and career counseling is provided. High performers in *both* tracks are rewarded with salary advances, increased prestige, greater responsibility, and choice assignments. Someone at the top level of management, such as the vice president or a director of research, supports the program in name and presence, giving credibility to the company's commitment to education.

Appendix D

Study Contributors

Pamela H. Atkinson is director of the Televised Instruction Program in the College of Engineering, University of California, Berkeley. During the year 1987 Ms. Atkinson was a fellow of the National Academy of Engineering in Washington, D.C., serving as study director for the project on career-long education of engineers. Ms. Atkinson's professional interests include adult learning, university-industry relations and technology transfer, engineering curriculum development, women and minorities in the professions, and career counseling. She is currently completing her doctorate in the School of Education at University of California, Berkeley.

Daniel Berg is currently Institute Professor of Science and Technology at Rensselaer Polytechnic Institute. Dr. Berg was appointed president of RPI in March 1985 after having served as acting president from May 1984. In 1953, Dr. Berg joined Westinghouse Electric Corporation, where he rose to the position of technical director. In 1977 he embarked on a career in academe when he was appointed professor of science and technology and dean of the Mellon College of Science at Carnegie Mellon University. He was later named provost at Carnegie Mellon, a position he occupied until 1983 when he accepted the position of vice president for academic affairs and provost at Rensselaer Polytechnic Institute. Dr. Berg is a fellow of the American Association for the Advancement of Science, American Institute of Chemists, and Institute of Electrical and Electronics Engineers. He is author of more than 75 technical management articles and books. He is active as a board member and technical adviser to many universities, federal agencies, and industrial organizations.

Jose B. Cruz is professor and chairman of electrical engineering at the University of California, Irvine. Before joining U.C.I. in July 1986, Dr. Cruz was professor and associate head of electrical and computer engineering,

and associate director of the Coordinated Science Laboratory, University of Illinois at Urbana-Champaign. His research areas include modeling and control of systems with multiple decision makers, intelligent control systems, and dynamic scheduling in manufacturing systems. Dr. Cruz served as president of the IEEE Control Systems Society in 1979, member of the board of directors of IEEE from 1980 to 1985, and IEEE vice president for publication activities from 1984 to 1985. He was elected IEEE Fellow in 1968. Dr. Cruz is author or coauthor of six books, and 185 papers.

Nell P. Eurich is senior consultant with the Academy for Educational Development, New York. Her background includes experience as a college administrator and professor. As a result of her book *Corporate Classrooms* (1985), Dr. Eurich has been invited to serve as consultant to corporations in the area of training and education. She also works with colleges and universities concerning the building of business and higher education partnerships. Her latest project is a study on adult learning in the United States for the Carnegie Foundation for the Advancement of Teaching.

Lyle D. Feisel is Dean of the Thomas J. Watson School of Engineering, Applied Science, and Technology at the University Center at Binghampton, State University of New York. From 1964 to 1983, he was a member of the faculty of the South Dakota School of Mines and Technology and head of that institution's Electrical Engineering Department from 1975 to 1983. In 1982 he held the Wachtmeister Chair in Engineering at the Virginia Military Institute. Dr. Feisel is a Fellow of the IEEE. He has served as president of the IEEE Education Society, as well as other organizations. He has had industrial employment with Collins Radio, Honeywell, IBM, and Northrop, and has consulted for private and public organizations. He is a registered professional engineer.

Martin Goland is president of Southwest Research Institute. Mr. Goland has served on numerous advisory committees including the Texas Governor's Council on Career Education, the Naval Research Advisory Board, the National Research Council's (NRC) Board on Army Science and Technology, and the NRC Commission on Engineering and Technical Systems, which he chaired. He is a fellow, past president, and director of the American Institute of Aeronautics and Astronautics and honorary member of the American Society of Mechanical Engineers.

Bernard P. Goldsmith is associate professor and assistant to the president of Carnegie Mellon University, Pittsburgh. For some 30 years he was responsible for mid-career courses and programs for managers and officers of technology-intensive enterprises. His experience includes teaching, administrative, and consulting assignments with universities, corporations, and government agencies in the United States and abroad.

Robert C. Gooding has worked as an independent consultant since his retirement from the U.S. Navy in 1976. He is currently chairman of the Columbia Research Corporation and of the National Sealift Corporation. Vice Admiral Gooding is past president of the American Society of Naval

Engineers and a member of the Society of Naval Architects and Marine Engineers and the U.S. Navy Submarine League.

Serge Gratch, now professor of mechanical engineering at GMI Institute, was affiliated with the Ford Motor Company from 1961 to 1986. He has held various research management positions, including director of the Chemical Sciences Laboratory. His activities and research interest at Ford focused on research on control of automotive emissions, pollution from manufacturing, atmospheric chemistry, biochemistry of toxic substances, fuels, lubricants, and other chemical and chemical engineering areas of automotive importance. Dr. Gratch has served as president of the American Society of Mechanical Engineers. He is also the regional editor of the *International Journal of Fracture*.

Charles W. Hoover, Jr., is chairman of the Committee on Education of AT&T Bell Laboratories. He has served since 1971 as executive director of the Interconnections and Power Technology Division. Dr. Hoover joined Bell Laboratories in 1954. His first research concerns focussed on the exploratory development of electronic switching systems and pulse compression radar. Dr. Hoover holds several patents and is author of a number of technical articles. In the fall of 1988 Dr. Hoover will become a professor of product realization engineering at the Polytechnic University of New York.

Craig Marks is vice president of technology and productivity planning at Allied Signal Inc. Until March 1988 he was vice president of science and technology at TRW Inc. Before joining TRW in 1983, Dr. Marks was with General Motors Corporation for 27 years where he held various positions on the engineering staff. From 1979 to 1983 he was executive director of the Environmental Activities Staff. Dr. Marks is a member of the Society of Automotive Engineers and the American Society of Mechanical Engineers.

Thomas L. Martin, Jr., is president emeritus at the Illinois Institute of Technology (ITT). Before joining IIT in 1974 as its president, Dr. Martin was dean of the College of Engineering at the University of Arizona from 1958 to 1963 and dean of the College of Engineering, University of Florida from 1963 to 1966. From 1966 to 1974 he was dean, Institute of Technology at Southern Methodist University. Dr. Martin serves as affiliated director at seven corporations, the Institute of Gas Technology, and the Chicago Museum of Science and Industry. He holds three patents and is author of six books and a variety of papers.

James D. Meindl is senior vice president and Institute Professor of Science and Engineering at Rensselaer Polytechnic Institute. Previously he was director of the Center for Integrated Systems and the John Fluke Professor of Electrical Engineering at Stanford University from 1967 to 1986. He serves as member of the Board of Directors of MA/COM Inc. and Performance Semiconductor Corporation. Dr. Meindl is a fellow of the American Association for the Advancement of Science and the Institute of Electrical and Electronics Engineers. He holds six patents and is the author or coauthor of more than 300 publications and the author of one book.

Jack N. Nielsen is chief scientist at the NASA-Ames Research Center. From 1966 to 1983 Dr. Nielsen was president of Nielsen Engineering & Research Inc. Dr. Nielsen is a former national director of the American Astronomy Society from 1966 to 1969. He is a fellow of the American Institute of Aeronautics and Astronautics and the Royal Aeronautical Society, and a member of the American Physical Society. He holds two patents and is author or coauthor of more than 195 publications.

Thomas K. Perkins is Distinguished Research Advisor to ARCO Oil & Gas Co. He previously was an assistant professor of chemical engineering at the University of Texas at Austin. From 1957 to 1981 he was research engineer, research director, and subsequently manager of production research at Atlantic Richfield Company. Dr. Perkins's areas of expertise comprise earth mechanics, hydraulic fracturing of the earth, permafrost behavior, arctic oil production technology, and pipeline technology. He holds 37 patents and is author or coauthor of 43 publications. He serves on the Department of Chemical Engineering Visiting Committee of the University of Texas at Austin, and on the Department of Chemical Engineering Industrial Advisory Council of Texas A&M University. Dr. Perkins is a distinguished member of the Society of Petroleum Engineers of AIME.

Kenneth A. Roe is chairman and president of the board of Burns and Roe, Inc. Mr. Roe is a founding member of the Columbia University Engineering Affiliates and chairman of the Columbia University Engineering Fund. Mr. Roe is a fellow of the American Association for the Advancement of Science, the Institute of Engineers of Australia, and the Institution of Mechanical Engineers, England. Mr. Roe served as first chairman of the American Association of Engineering Societies in 1980 and is past president of the American Society of Mechanical Engineers. He serves as director on the executive committee of the American Nuclear Energy Council.

Chauncey Starr was founding president and vice chairman of the Electric Power Research Institute. He is now President Emeritus. Dr. Starr came to EPRI from the University of California, where he held the deanship from 1966 to 1973 at the School of Engineering and Applied Science. Dr. Starr has served on numerous governmental and quasi-governmental panels and boards such as the President's Task Force on Science Policy of the Office of Science and Technology, and the Research and Technology Advisory Council at NASA. He is a fellow and formerly founder, director, and president of the American Nuclear Society and formerly director of the American Association for the Advancement of Science. Dr. Starr is a foreign member of the Royal Swedish Academy of Engineering Sciences.

Dale F. Stein is president and professor of Metallurgical Engineering at Michigan Technological University. Dr. Stein served as president of The Metallurgical Society, American Institute of Mining, Metallurgical and Petroleum Engineers (AIME) in 1979, as director of AIME from 1979 to 1981, and as vice president in 1981. Dr. Stein is author or coauthor of more than 60 publications.

Leo J. Thomas is a senior vice president and general manager of life sciences at Eastman Kodak Company and vice chairman of Sterling Drug Inc. Dr. Thomas joined Eastman Kodak in 1961. He has been a member of the Engineering Research Board of the National Research Council, chairman of the Resource Development Committee of Department of Chemical Engineering of the University of Illinois, and member of the Trustees' Visiting Committee to the College of Engineering and Applied Sciences of the University of Rochester. Dr. Thomas is a member of the American Association for the Advancement of Science.

Marc S. Tucker is president of the National Center on Education and the Economy, a nonprofit organization established in 1988 to continue the policy development work begun by the Carnegie Forum on Education and the Economy, which Mr. Tucker served as executive director through December 1987. Prior to joining Carnegie Corporation, Mr. Tucker conducted research on the use of computers and telecommunication technology in education. From 1972 to 1981, he was at the National Institute of Education, where he served as Associate Director for Education Policy and Organization. During his career, Mr. Tucker has been involved in mathematics and science curriculum development, technical assistance programs serving the needs of low-income communities, and educational broadcasting.

Eric A. Walker is president emeritus at the Pennsylvania State University. Dr. Walker is former president of the American Society for Engineering Education, the Engineers' Joint Council, the National Academy of Engineering, and the National Science Board. Dr. Walker holds four patents and is author or coauthor of more than 300 publications. Dr. Walker is adviser to industry on research and development programs and methods of moving research results to commercialization. He consults with universities on problems of planning, financing, and organizing for new ventures such as outreach programs and affiliation with high-technology parks.

F. Karl Willenbrock is executive director of the American Society for Engineering Education. For the previous 10 years, Dr. Willenbrock was Cecil and Ida Green Professor of Engineering at the School of Engineering and Applied Science, Southern Methodist University, also serving as dean of the school from 1976 to 1981.